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ABSTRACT

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The purpose of this research was to address the problem of facilitating group decision performance in a dynamic task situation which involves uncertainty through the use of graphic information presentation and decision heuristics. The investigation involved a laboratory experiment with groups of three performing a dynamic group choice task (the Team Resource Allocation Task). Each team completed a total of 32 trials, half of which were presented at a fast rate of speed and half at a more moderate speed. The teams had insufficient resources to respond to every event presented, so they were advised to identify and commit resources to the most valuable combinations of events. Visual coding schemes for presenting the events varied between teams as did the presence or absence of decision heuristics provided by the researcher.

The most important finding of this research was that aids which guided the decision process had a much greater impact on decision quality in a dynamic group choice task than did the form in which information was presented. This finding suggests that how decision makers use technology (their decision process) is at least as important as the technology itself for supporting decision making. Additional research should be applied to exploring how to aid the decision process.

Other findings included the following: (1) Teams performed better under moderate time pressure than under high time pressure, (2) Teams performed better with practice, (3) Heuristics had a greater effect on decision quality under moderate time stress than under high time stress, and (4) Heuristics had an immediate and lasting effect on decision quality. (SDW)

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AN EXPLORATION OF TEAM INFORMATION PROCESSING
IN A DYNAMIC GROUP CHOICE TASK
INVOLVING UNCERTAINTY

A THESIS
SUBMITTED TO THE FACULTY OF THE GRADUATE SCHOOL
OF THE UNIVERSITY OF MINNESOTA

BY

DOROTHY JEANNE MCBRIDE

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

1988

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1.0 INTRODUCTION

In spite of the myriad of studies of group performance completed, 'we still know very little about why some groups are more effective than others. We know even less about what to do to improve the performance of a given group working on a specific task.' [HACK83, p. 331] Computer-based support of group decision making and the explicit discussion of decision strategies have both been offered as means to improve group performance. This research examines how group decision making performance is affected by the provision of a Group Decision Support System (GDSS). In this study two types of decision support are provided to decision making groups, one type involving the information presented for decision making and the other type representing an aid to the process used by the group to make a decision. The goal of the research is to investigate the role that may be played by each of these types of decision support on group decision making performance.

This opening chapter identifies the general problem addressed by the research, details the purpose of the study, and explains the relevance of the research in general and of the chosen experimental task in particular. The final four sections of the chapter introduce the research approach, present the limitations and key assumptions of the study, identify the contributions and strengths of the research, and outline the contents of the remaining chapters of the thesis.

1.1 The Problem

Research in decision making has followed a number of different avenues, some more developed than others. There are ample opportunities among the less developed areas for further research. For example:

-- Research in the computer-based support of decision making groups is only beginning [GALL85]. Additional research-based knowledge about decision processes is essential for the development of more effective Group Decision Support Systems (GDSS); at the same time, the development and application of GDSS tools as experimental treatments can contribute greatly to studying group decision processes [KRAE84].

-- The number of variables involved in and the complexity of group decision making situations make studying these situations difficult, so empirically based knowledge about group decision making processes is limited [KRAE84]. Among the variables that Hackman and Morris present as controlling factors in group performance are the task performance strategies used by group members [HACK83]. There is much to be discovered empirically about how groups might use heuristics as part of a strategy to support their decision making processes.

-- There is a growing body of research concerning the impact of computer-based business graphics on decision making. The results of graphics research, however, have been inconsistent [DESA84, JARV85]. The inconsistent results have been attributed largely to task differences [DICK86, JARV86a]. Research is still needed to identify appropriate matches between the decision maker's task and the means of presenting information to the decision maker.

-- Laboratory studies that have attempted to explain improved decision outcomes associated with computer-based decision support have been especially limited. The missing explanations can be discovered by examining how the decision making process changes with variations in the decision support provided [BENB84].

No single study can fill all the gaps in even one of these areas, but any study of decision making should be aimed at contributing some knowledge to one or more of the areas. The following purpose statement identifies the gaps which are targeted in this research.

1.2 Research Purpose

The purpose of this research is to explore the impact of variations in information presentation and of decision process interventions on group decision quality. In particular, this research addresses the problem of facilitating group performance in a dynamic task situation which involves uncertainty through the use of graphic information presentation and decision heuristics.

1.3 Relevance of the Research

> Nearly every facet of our society -- political, legislative, judicial, economic -- functions through decisions made by groups.... The functioning of every business, educational, and political organization relies on decisions made by management teams [FISH80, p. 2].

Group decision making is indeed pervasive in our society, and Huber [HUBE84a] predicts that group decision making in the future will need to be even more frequent and faster and will need to account for greater complexity in the decision situation. He expects that organizations will improve the effectiveness of their decision making groups through the adoption of more sophisticated group technologies. The more that can be learned about the impact of group technologies on decision making teams, the more organizations will be prepared to cope effectively with the demands of an information-intensive future.

This study extends knowledge of the effects on group decision outcomes of two factors: computer-based graphic information presentation and the explicit provision and discussion of decision heuristics. In particular, the study extends knowledge about the effects of both factors in a dynamic decision environment, an environment that has not been extensively studied. In addition, a major contribution of this research is the opportunity to explain <u>how</u> variations in decision support contributes to the effectiveness of decision making groups.

1.4 <u>Relevance of the Experimental Task</u>

The Team Resource Allocation Problem (TRAP), the experimental task for this research, places the decision making team in a decision environment that has not been extensively studied, but that is characteristic of the post-industrial society envisioned by Huber [HUBE84b]. Results of the research are applicable in any organization in which teams of decision makers must make choices under time pressure in dynamic, uncertain situations.

For example, among a computer operations team's basic duties is responding to system messages displayed on the computer console. A number of messages may be displayed simultaneously on the same console, and the situation is constantly changing. The operations team has to choose from among the messages presented the one that requires the highest priority response. Because of the high turnover and the resulting low experience level among computer operators, organizations are interested in facilitating operator training and task performance. Sperry Corporation, in particular, is sponsoring research aimed at improving operator task performance through improvements in the computer-operator interface [VANW86]. The results of this research are applicable in the development of such user interfaces and in the development of training programs.

Public and private crisis intervention teams could also benefit from using systems that incorporate research findings on supporting team decision making. Steven Fink, President of Lexicon Communications Corporation, a management consulting firm specializing in crisis management, insists that 'Every crisis demands a crisis management team' and identifies the need to collect the appropriate information and route it to the proper decision makers [FINK86, pp. 57, 65]. Crisis teams require quick, reliable, and clear information to support their decisions at times when stress and time pressure can lead to information overload and miscommunication [HOUS86]. An information system designed to support crisis management must 'minimize message ambiguity, information filtering and distortion, and conflicting instructions' [HOUS86, p. 393]. The results of this study aid in understanding how to minimize ambiguity, filtering, distortion, and conflicting instructions in crisis management situations through explicit discussions of decision strategies and appropriately designed information displays.

Additional specific applications of the research results involve decision making teams in the following decision environments:

-- Manufacturing/process control. Teams must monitor ongoing operations, identifying and responding to problem situations.

-- Air traffic control/military command and control. Information in these control situations 'usually concerns the past, present, and future location, identity and certain other attributes of various objects' to which teams must respond quickly and accurately [WOHL84].

-- Financial markets. The stock market is volatile, and financial managers must react quickly to new quotations for the benefit of their clients.

In each of these environments, team decision making can potentially be made more effective through use of decision support which incorporates the results of this research.

1.5 Research Approach

The study was a laboratory experiment, which provided the means for controlled tests of the effects of specific independent variables. As recommended by Benbasat, the experiment was conducted with multiple dependent variables and using multiple methods of measurement [BENB84]. The dependent variables measured group performance and perceptions of workload. The measurement methods used were computer tracking and questionnaires. These methods allowed the analysis of both the decision outcomes (what effect the independent variables had on decision outcomes) and the decision process (how and why the independent variables had an influence).

1.6 Limitations and Key Assumptions

1.6.1 Limitations. The study is limited in the following ways:

- -- The study is specifically oriented to exploring the performance of three-person teams with the TRAP. The results may not be generalizable to other group sizes or to other tasks.

- -- Only a limited set of the variables involved in the group process were examined. Practical limitations demand that many factors be reserved for other studies.

- -- Only a limited number of possible treatments within each of the variables were examined. Different information presentation approaches, sets of heuristics, or levels of time pressure could yield different results, but practical limitations again demand that many variations be reserved for other studies.

1.6.2 Assumptions. The study was based on the following key assumptions:

- -- College students are suitable subjects for the research. The characteristics of the college students who served as subjects for the experiment may not exactly match those of the individuals who would ultimately use systems based on the results of the study. Especially for exploratory research [DICK86], however, the use of students as surrogates for decision makers should not discredit the study [REMU86].

- -- Factors such as the mix of men and women on a team, the seating position of a male on a mostly female team (or of a female on a mostly male team), and the mix of levels of individual experience with personal computers/computer terminals and video games on a team would not materially affect the results or would be sufficiently accounted for through random assignment of treatments. This assumption was supported in preliminary analysis of the experimental results.

- -- Discriminating among the five levels in the information coding schemes would remain within the limits of human information processing [MILL56]. The subjects were tested to assure that they could discriminate among and understand the meanings of the five levels in the code they used, but the test was administered under static conditions with no time pressure.

The assumption was that the dynamic conditions and the time pressure of the experimental situation did not place the codes beyond the limits of human information processing.

1.7 Contributions of the Research

A major contribution of the study is that it extends knowledge about information representation and heuristics effects in an important decision context that has not been extensively studied. In describing the likely nature of post-industrial organizations, Huber predicts that organizational decision making will be more complex; concurrently, there will be demands for organizational decision making to be both more frequent and faster. To achieve the requisite decision group efficiency and effectiveness, organizations will be motivated to integrate computer and communication technology into their decision processes, especially for the high stress conditions facing crisis decision groups [HUBE84b]. This research contributes to determining the most appropriate applications of information technology to group decision making in post-industrial organizations.

Other major strengths of the study are as follows:

- It is founded in established reference discipline theory [KEEN80, JARV85, DESA84].

- It builds on both the managerial graphics research stream at the University of Minnesota and the team technology research stream at the Harry G. Armstrong Aerospace Medical Research Laboratory. The sharing of definitions, concepts, and measurement instruments helps to build a cumulative tradition of MIS research [KEEN80, DICK86].

- The equipment used represents state-of-the-art technology in graphics terminals, yet the study focused on the effectiveness of the support provided to decision makers rather than on the technology itself [KEEN80].

- The results of the study have practical application both to the sponsoring organization and to other organizations involved in related tasks [KEEN80].

- The dynamic group task used simulates a decision context that has not been extensively studied.

- The study provided opportunity for a limited examination of the cognitive processes underlying the decisions made [PAYN78].

1.8 Organization of the Thesis

Chapter 2 reviews significant prior research. Chapter 3 presents a conceptual model placing the study in context, identifies the variables of interest, and develops hypotheses from the relevant theory and research results. Chapter 4 provides a detailed explanation of the experimental task and a full description of the research method. The research outcomes are presented in Chapters 5, Analysis of Results, and 6, Discussion of Results and Conclusions.

2.0 SIGNIFICANT PRIOR RESEARCH

The specific purpose of this research is to address the problem of facilitating group decision performance in a dynamic task situation which involves uncertainty through the use of graphic information presentation and decision heuristics. The following sections present highlights of prior research relevant to the areas indicated by each of the underlined phrases in the purpose statement.

2.1 Group Decision Making

In a review of group research contributions over a period of three years from the disciplines of psychology, sociology, communications, education, and administrative sciences, McGrath and Kravitz determined that about 40 percent of the studies were concerned with the effectiveness of group task performance [MCGR82]. The large proportion of performance-oriented studies continued an historical tendency to focus a major share of research effort on such issues as comparing group to individual performance and identifying factors that affect group task performance. Among the tasks most frequently used were those identified in McGrath's Task Circumplex as choice tasks, both intellective and decision-making tasks [MCGR84].

Group decisions are different from those of individuals. In spite of the potential problems in reaching consensus and the opportunity for conflict, a group tends to make decisions of higher quality than the average performance of individual members of the group [MINE84, MCGR84]. Group decision making, however, also tends to be inefficient and slow; groups tend to proceed in bursts of activity, jumping from one issue to another frequently, while individuals seem able to sustain concentration on a single issue [FISH80].

2.1.1 Process Gains and Losses

Huber suggests that a group's actual decision-making effectiveness equals its potential effectiveness plus gains resulting from group processes minus losses resulting from group processes [HUBE82]. Groups gain because they have more resources, more sources of information and of new ideas, and more perspectives for critical analysis of ideas [FISH80]. They generate more alternatives and are better at analyzing the relative advantages and disadvantages of the various alternatives [TURO82].

On the other hand, group processes can contribute to losses in decision effectiveness. For example, decision quality can suffer when individual group members dominate the group process beyond the merits of their contributions, when group members miscommunicate, or when there are group pressures to conform [HUBE82]. The complexity of group communication limits the group's effectiveness especially when group productivity depends on the coordinated efforts of group members [HACK83]. Groups also fail to reach their potential because they are ineffective at identifying members who could contribute most to the group decision. For example, the quality of a group decision has been shown to be no different from the quality of the individual decision selected as best by members of the group. By contrast, the group decision was inferior to the individual decision that actually was the best of the decisions made by members of the group [MINE84].

2.1.2 Task Effects on Group Performance

Group decision processes vary according to the task. Intellective tasks such as the TRAP task used in this study have a correct answer. For such tasks, the decision scheme that best fits group performance has been labelled 'truth, supported, wins' [MCGR82]. In other words, the group accepts a solution as correct if at least two members know it to be correct. A solution presented by only one member, even if it is the correct solution, may not be readily accepted unless the solution can be explained easily and is intuitively compelling once revealed. Groups accept solutions to 'eureka' problems, then, on a 'truth wins' basis [MCGR82]. Other factors associated with the task (e.g., time pressure) also influence group performance [ISEN81]. Specifically, Isenberg found that increased time pressure led to less equal sharing of communication time among group members, more salient leadership, and less accurate decisions.

2.1.3 Computer-based Support of Group Decision Making

Examining the impact of computer-based support of group decision making is a relatively new area of study. A Group Decision Support System (GDSS) has been defined as 'an interactive computer-based system which facilitates solution of unstructured problems by a set of decision makers working together as a group' [DESA85]. GDSS results, although limited, provide some basis for understanding the impact of computer-based support of group decision making.

Only a small number of GDSS' have been developed [HUBE84a]. Of those designed, most have been intended to facilitate decision processes that fit the rational model by helping to identify and clarify decision alternatives [KRAE84]. Any one system, however, tends to support only a small set of specific tasks [HUBE84a].

Steeb and Johnston [STEE81] compared the performance of groups with and without computer-based aids in solving a complex international crisis problem. The system elicited a decision tree from the group based on pooled inputs from the members. Groups with computer support considered more factors, scored better on measures of the content and breadth of their solutions, and developed more detailed courses of action. They were also more confident in their decisions and more satisfied with the process. Groups without computer support had the advantage only in completing the process in less time.

Turoff and Hiltz [TURO82] also compared the performance of groups with and without computer-based support. The task was a semistructured survival problem, and the computer-based support involved computer conferencing and a decision aid in the form of feedback concerning the degree of consensus achieved. Communications in groups operating with computer conferencing facilities were more task-oriented than in groups operating face-to-face. Second, groups with either the decision aid or formal leadership reached greater consensus in computerized conferences, but groups with both the decision aid and formal leadership reached no greater consensus than groups with neither the decision aid nor formal leadership.

Group Decision Support System use has also been shown to enhance decision quality for groups performing a problem-solving task [LEWI82], a problem-finding task [GALL86], and idea generation in support of an organizational planning task [APPL86]. Another study provided partial support for the contention that use of a GDSS provides for more even distribution of influence behavior among group members performing an intellective task [ZIGU88]. On the other hand, GDSS use did not increase group consensus on a preference allocation task [WATS87].

Nearly all the studies of group decision performance have used static decision tasks; i.e., the task environment remains stable during the decision process. The next sub-section reviews some studies of decision making in dynamic task environments.

2.2 Dynamic Decision Making Tasks

Rapoport suggested that a decision making situation can be described as dynamic when most or all of the following characteristics are involved: (1) decision makers make a series of decisions over time; (2) previous decisions or other factors may change task requirements over time; (3) the results of previous decisions may determine what information is available for further decisions; (4) the results of any decision may impact future events [RAPO75].

In spite of the fact that real decisions are made primarily in dynamic rather than static situations [LITT86], research in dynamic decision making has been extremely limited. One reason for the limited research has been that dynamic decision models "are so complex and require so many assumptions that the interpretation of experimental results is typically ambiguous" [SLOV77, p. 14]. In addition, many studies have been plagued by the "curse of insensitivity" [RAPO75]. In other words, when decision makers are told to optimize their performance and are compared on the basis of payoffs received, large variations in decision behavior typically result in very small differences in payoff. On the other hand, Slovic, Fischhoff and Lichtenstein suggest that there are some important human factors questions worth studying in the area, including "How do variations in the basic system (e.g. different instructions or information displays) affect people's performance?" [SLOV77, p. 26].

2.2.1 Non-Simultaneous Choice

Some studies of dynamic decision making have explicitly established decision points at which decision makers had the option either to make a final decision immediately or to seek additional alternatives before making a final choice. The point at which a final decision is made provides some evidence, for example, about whether the decision makers have adopted a satisficing or a maximizing strategy. Olander found that a maximizing strategy best described individual behavior. There were, however, some individuals who tended toward satisficing when they had very little information about the alternatives that would be available with search [OLAN75].

2.2.2 Supervisory Control

Other studies have concentrated on tasks related to supervisory control of unstable systems, such as those faced by air traffic controllers, manufacturing process controllers, and power system regulators. The human operator's task in these problems is to monitor various sources of information and to select and act on those events that demand their intervention. Such studies often compare decision maker performance to a model of idealized performance. Although further work is called for on the effects of uncertainty in such tasks, there have been some consistent findings. Many decision makers performed very well, performance improved rapidly with practice, and some subjects either consistently under-controlled or over-controlled the system [RAPO75].

Pattipati, Kleinman, and Ephrath [PATT83] also focussed on supervisory control problems using a dynamic decision task adapted from a task designed by Tulga and Sheridan [TULG80]. The Pattipati et al. task presented up to five events at a time on a cathode ray tube (CRT) screen. Each event was represented as a rectangle that appeared initially at the left edge of the screen, moved across the screen to the right at various speeds on one of five lines, and disappeared upon reaching the right edge of the screen. No more than one rectangle at a time appeared on any one line. The height of each rectangle represented its payoff and could be one, two, or three units. The number of dots displayed on the rectangle represented the number of seconds required to process the event and could range from one to five seconds. Subjects processed an event by pressing a button corresponding to the line on which the rectangle appeared. Subjects were told to maximize their accumulated payoff and were told their scores at the end of each 90-second trial. Pattipati, Kleinman, and Ephrath were not directly interested in comparing task performance among individuals, so they did not report performance data. Instead, they developed a Dynamic Decision Model (DDM) to describe human performance on the experimental task.

The DDM was based on the assumption that, subject to human limitations, well-trained participants would behave rationally (would use subjectively expected value to choose among available rectangles). The model took into account such factors as the processing time required for an event, the time available to work on the event, the relative importance (reward value) of the event, human reaction delays, and human inconsistencies in responding to similar events. Empirical studies showed that their model more accurately predicted human performance than did models based on task scheduling theory [PATT83].

2.2.3 Team Resource Allocation Problem

Brown and Leupp [BROW85] extended the experimental task developed by Pattipati, Kleinman, and Ephrath in developing the Team Resource Allocation Problem (TRAP). The major extension involved adapting the task for use with groups of three decision makers who were expected to coordinate their responses to the task. All the events in a TRAP trial moved at the same speed and required the same processing time, but trials could run at different speeds with event processing time adjusted relative to the trial speed. TRAP presented a maximum of 11 events on the screen at a time and expanded the range of event values. (See Chapter 5 for a full description of the TRAP.)

In a baseline study using the TRAP, Brown and Leupp determined that performance of three-person teams was not strongly affected when the TRAP was presented on one large screen display rather than three individual CRT's. Although the specific results concerning large screen technology was not a concern in this research, the Brown and Leupp study did establish a research methodology on which additional studies could be built [BROW85]. Continued use of variations on the TRAP throughout a series of experiments, with retention of the underlying measuring tools, overcomes the difficulties associated with a proliferation of measuring instruments as identified by Jarvenpaa et al. [JARV85].

The environment for decision making in real organizations is not only dynamic; it is also uncertain. The next sub-section outlines what research has shown concerning decision making under uncertainty.

2.3 Decision Making Under Uncertainty

A state of uncertainty exists when a decision maker has incomplete information on which to base the decision. Decisions under uncertainty have often been subcategorized as either decisions under risk or decisions under uncertainty. Decisions under risk involve knowledge of all the possible decision outcomes and their probability distribution; decisions under uncertainty involve knowledge of all the possible decision outcomes but not their probability distribution [MUHS81].

2.3.1 Expected Utility Theory

The dominant theory under which study of decision making under uncertainty has been conducted is the subjective expected utility model [SLOV77]. It has been used as both a normative and a descriptive model of human risky choice behavior [KAHN79]. According to the model, 'rational' managers weight the utilities of outcomes by their probabilities and choose among alternatives on the basis of the highest expected utility [MUHS81]. Expected utility theory, however, has frequently been criticized as inadequate to describe human behavior. People are, for example, systematically biased in their perception of uncertainty [GRET78].

2.3.2 Human Biases

Human biases result from applying mental operations that simplify judgments but that also lead to errors. Tversky and Kahneman [TVER74] have identified three such mental operations (heuristics): representativeness, availability, and adjustment and anchoring. The first heuristic, representativeness, can lead to errors through insufficient attention to base rates, sample sizes, or the reliability of evidence. The availability heuristic biases judgments of probabilities according to how readily examples come to mind. Finally, people tend to 'anchor' on and then to make adjustments from some starting probability estimate, but the adjustments tend to be smaller than the evidence warrants. Therefore, different 'anchors' yield different probability estimates.

2.3.3 Prospect Theory

In addition to being biased in their judgments of uncertainty, humans are often inconsistent in their choices. They frequently do not use obvious optimal strategies for risky choice problems [LITT86]. To account for human inconsistencies, Kahneman and Tversky [KAHN79] have proposed prospect theory as an alternative to expected utility theory. A prospect is one of the 'gambles' or probabilistic options from which the decision maker is to choose.

According to prospect theory [KAHN79], people go through two phases in choosing among prospects: an editing phase and then an evaluation phase. In the editing phase, people simplify the statement of the prospects through such operations as coding (formulating the prospect in terms of gains and losses from the current position), rounding off probabilities and outcomes, and discarding extremely unlikely outcomes. In the evaluation phase, the value of each outcome is weighted, not by the probabilities of the outcomes, but by a decision weight that tends to overweight very low probabilities and to underweight all other probabilities.

The combined effects of the editing and evaluation phases account for many of the inconsistencies humans exhibit in risky choices. For example, prospect theory provides an explanation for why humans tend to select certain gains over merely probable gains with comparable or even higher expected value and to select probable losses over certain losses [KAHN79].

2.3.4 <u>Alternative Theories</u>

Additional theories have been offered as alternatives to prospect theory for explaining human risky choice behavior. For example, regret and disappointment theories each suggest that the feelings one anticipates having upon resolution of the gamble are factors in evaluating the alternatives [LOOM82, BELL82, BELL85, LOOM86]. Regret is the feeling an individual has when it appears, after the fact, that he has made the wrong choice (the horse he almost played wins). Disappointment results when outcomes fail to match up to expectations (his number wins the lowest prize in a lottery). According to regret and disappointment theory, then, human inconsistencies in risky choice behavior can be explained as rational tradeoffs between objective utility and avoidance of or insurance against anticipated regret or disappointment.

2.3.5 Risky Choice Behavior in Groups

Some early research concerning risky choice behavior in groups suggested that groups tended to take greater risks than the group members would as individuals, a finding labelled the 'risky shift' [FISH80]. Subsequent studies, however, failed to support the generalizability of the risky shift. Instead, it seems that groups may shift ('choice shift' or 'group shift'), but not always in the risky direction; factors such as the significance of the choice outcomes apparently influence the direction and magnitude of the shift [MUHS81].

The difficulties of making decisions under dynamic, uncertain conditions call for aids for the decision maker. Among the alternative decision aids are computer-based graphics and decision heuristics, which will be addressed in the following two sub-sections.

2.4 Graphic Information Presentation for Decision Making

In reporting on research opportunities in the decision and management sciences as identified by the National Science Foundation, Little [LITT86] included the need to study the effectiveness of alternative computer-based forms of presenting information. He and others have noted especially that state-of-the-art computer graphics technology provides the means and the motivation for research in the use of color and graphics [LITT86, JARV86b, DAVI83].

2.4.1 Tables versus Graphs

The body of research in the use of business graphics has, in fact, been growing. Early studies focused largely on comparing the effectiveness of tabular and graphic presentations of information for decision support with mixed results [IVES82, DESA84]. Among the reasons cited for the conflicting results are the following [BENB86B, JARV85]:

a. Inappropriate experimental designs

b. Differences in types of graphics used (bar charts, pie charts, etc.)

c. Lack of either a theoretical or an empirical basis for hypotheses

d. Task differences

Improved technology, used according to established guidelines for preparing graphics [IVES82, OLEV85], can now provide high quality graphics for fair comparisons with well-prepared tabular formats. In addition, researchers have started to account explicitly for their research bases and for the effects of task differences in their results.

2.4.2 Research Programs

Researchers have also stressed the importance of studying the use of graphics in programs of research rather than in one-shot experiments [BENB86c, DICK86]. Dickson et al. reported on a series of experiments using three different tasks; the relative effectiveness of graphical and tabular formats varied with the demands of the assigned task. They recommended further investigations of task content, task complexity, and task structure as dimensions of the task environment as it affects the use of graphics [DICK86]. Benbasat et al. also conducted a series of three experiments, but using a single resource allocation task; their results reinforced the concept that information presentation needs to be matched with the demands of the task. In their experiments, graphical formats allowed faster decision making and were superior for identifying patterns in the data; tabular formats allowed higher quality decisions and were superior for identifying specific data values [BENB85, BENB86a, BENB86b, BENB86c]. In a program of research using the Team Resource Allocation Problem (TRAP), decision performance using a graphic representation of the task was found to be superior to decision performance using a tabular representation of the task, especially under high time stress conditions [WILS87]. In that the TRAP is essentially a monitoring application in which the data presented is inherently dynamic, these results support Davis and Swezey's findings that computer graphics are particularly appropriate for dynamic data presentation [DAVI83].

Since a graphic representation has been established as superior to a tabular representation for presenting information in a dynamic group decision task (TRAP), comparisons among alternative graphic representations are appropriate. Graphic representations of information can vary along a variety of dimensions. For example, Ives [IVES82] identified five basic visual input channels available to the human information processing system: color, relative position, brightness, movement, and shape. Appropriate use of these channels has been shown to aid in target identification, a fundamental aspect of the TRAP.

2.4.3 Feature Integration Theory

Treisman and Gelade's Feature Integration Theory suggests that for tasks such as visual search and target identification and localization, visual cues that are conjunctions of features (e.g., color and shape) require focused attention and seem to be processed serially. Cues having only a single feature (e.g., color alone) may be processed in parallel (i.e., more quickly). Further, when multiple conjunctively coded objects are presented under time constraints or when attention may be diverted, an individual may incorrectly combine features of unattended objects and falsely report the presence of specified objects (illusory conjunctions). Thus, especially under conditions when attention may be diverted or overloaded, subjects perform visual search tasks more quickly and accurately when the objects vary on a single dimension rather than as conjunctions of features [TREI80, TREI82].

Because other researchers had found qualitative changes in performance on visual tasks with extended practice, Treisman and Gelade examined the effects of practice on searching for conjunctively coded objects. They found no indication of movement from serial to parallel processing over 13 blocks of practice [TREI80].

Others have tempered Treisman and Gelade's findings. Egeth et al. suggest that search for conjunctively coded objects may proceed with an initial parallel elimination of all objects lacking the more salient specified feature. A second stage in the search involves serial examination of the remaining objects for the specified conjunction of features [EGET84]. For example, a search for red-A objects may start by eliminating all objects that are not red and then searching serially for A's among the red objects. Sagi and Julesz agreed that single-featured objects are detected in parallel, but they found that precise identification of a detected object requires focal attention on that object [SAGI85]. Performance differences, however, depend more on the time required to locate the object than on the time required to identify the value of the object [CHRI83].

2.4.4 Color versus Letters

Considering only single-featured visual codes, both alphanumerics and color have been evaluated as excellent for use in locating objects, although alphanumerics are superior for precise identification of the object [DAVI83]. Research has also shown that more distinctive colors and shapes allow faster search than less distinctive ones; i.e., search is faster for distinguishing red from green or P from Q than for distinguishing blue from green or O from Q [TREI80, GHAN82].

A considerable body of research exists concerning the relative effectiveness of visual codes for search and identification tasks, particularly comparing color to other codes. Christ reviewed 42 studies published between 1952 and 1973 on the effects of color on visual search and identification performance. In ten studies on the accuracy of identifying objects in a unidimensional display, letters were superior to color, and the advantage for letters increased with increases in the density of the display and with decreases in exposure time. On the other hand, in four studies on the time required to locate objects, color was superior to letters, although the difference was less than that found between color and other visual codes (size, brightness, geometric shapes, etc.) [CHRI75].

In a more recent set of experiments, Christ determined that there are "no clear and consistent advantages for any one visual code set over the others" [CHRI83, p. 83] Where he found differences in the relative effectiveness of the codes, they depended on other display conditions (e.g., density of the display), the task, and the dependent measure used. Differences did exist under those conditions most closely related to the conditions established for this study; for locating a specified object among 12 randomly located objects in a display, location times were shorter for colored dots than for letters [CHRI83]. Christ has also demonstrated that extended practice with a visual task tends to attenuate any differences in performance based on use of different single-featured codes (letters, digits, familiar geometric shapes, and colored dots) [CHRI75, CHRI83].

Although additional work is required to clarify how best to match visual codes with task conditions, appropriate graphic displays of task information could contribute to decision making effectiveness. The decision maker's decision process, which is also an important variable contributing to decision making effectiveness, may be influenced by decision heuristics. Studies about the impact of decision heuristics on decision making will be addressed in the following sub-section.

2.5 Heuristics for Decision Making

A number of studies have described the heuristics and biases that humans typically use in a variety of task situations [HUBE85; SLOV77]. Much has been written, for example, about human biases in situations involving uncertainty and our failure as intuitive statisticians. Humans seek to reduce the complexity in the problems they face through the use of heuristics, which reduce the number of alternatives considered to a manageable size [FULL78].

The heuristics often work well but may lead to serious errors [KLEI82b]. For example, human preference for simplicity led to suboptimality in a study exploring people's choices between conflicting analyses of a decision problem [KLEI82a]. Klein found that people were more confident in their decisions with a simple intuitive analysis than with a conflicting but mathematically accurate analysis. He called for additional research on training decision makers to recognize their biases and to know when to legitimately use heuristics.

Given that the heuristics that decision makers adopt are sometimes biased, some effort has been given to examining the impact of attempts to reduce the biases. Procedures for reducing human bias are collectively known as debiasing methods [FISC82]. The nature of a particular debiasing method depends on the perceived source of the bias: if the bias results from a faulty task, fix the task; if the bias results from a biased but perfectible decision maker, provide training/feedback [FISC82]. Assuming a perfectible decision maker in a probabilistic task, training could take the form of providing prescriptive decision rules, or alternate heuristics, with the intent of determining their impact on decision performance.

Cats-Baril and Huber examined the impact of providing decision-aid heuristics on the performance of an ill-structured career planning task. The task required participants to identify career objectives, generate alternative strategies for achieving the objectives, and prioritizing the alternatives. Some participants were provided with a purpose-expansion heuristic designed to increase the number of objectives and alternatives considered and to explore the alternatives more thoroughly. Participants with heuristics performed better both on objective measures of the number of issues addressed and on expert evaluations of the quality of the plans produced. The researchers called for additional studies on the impact of different types of heuristics on tasks with different levels of structure [OATS87].

Johnson and Payne have defined risky choice heuristics as rules that systematically simplify the choice among alternatives by disregarding some elements of the problem space (ignoring some alternatives, selectively examining outcomes, ignoring some event information, etc.). Different heuristics are based on different simplifications of the choice. Using computer simulation, they compared six heuristics under a variety of conditions for their accuracy (conformity to a choice using expected value) and mental effort required. Their data suggested that 'heuristics, in at least some task environments, can approximate the accuracy of normative rules with substantial savings in effort' [JOHN85, p. 408].

Kleinmuntz [KLEI85] also used computer simulation to study a variety of heuristics for medical diagnosis. He determined that the relative performance of the various heuristics depended more on time pressure and feedback on the outcome of previous treatments than on factors such as disease base rates. Kleinmuntz concludes in part that additional research is needed on how task knowledge is acquired and how heuristics are selected.

Arkes et al. studied conditions under which individuals would choose not to use helpful but imperfect decision heuristics in a probabilistic task. In one experiment, subjects were told (correctly) that using the heuristics provided would result in 70 percent accuracy in their judgments. Those who were warned that deviating from the heuristic would result in degraded performance and who received no monetary incentives for performance did best, matching the 70 percent accuracy level. Those who were encouraged to try to improve on the heuristic or who received monetary incentives for performance deviated from the heuristic and judged less accurately. Those who received no immediate feedback on the accuracy of their judgments also outperformed those who did receive feedback; feedback about an incorrect judgment tended to cause deviation from the heuristic and degraded performance on the following trial. In a second experiment, the heuristic provided resulted in 75 percent accuracy. Those who had expertise in the task context (or who thought they did) tended to use the heuristic less and to perform worse than those without expertise [ARKE86].

2.6 <u>Summary of Relevant Literature</u>

Group decision processes vary depending on the task. The group decision process that best fits actual group performance for dynamic intellective tasks of the sort used in this research is 'truth, supported, wins' [MCGR82]. Uncertainty in the task affects group decision performance in that people are biased in their perceptions of uncertainty, and they tend to adopt less than optimal strategies for risky choice problems [LITT86]. Debiasing methods, such as providing task training using decision rules (heuristics), lead decision groups to adopt more appropriate decision strategies, and thus positively impact decision performance [FISC82].

A considerable body of research has focused on supporting decision making through the presentation of information via computer graphics. Research results, especially from early studies, have been mixed, but it is clear that task differences have an impact on how effectively graphics can be used to support decision making [DICK86]. A graphic representation has been established as superior to a tabular representation for presenting information in the experimental task chosen for this research [WILS87]. Feature integration theory suggests that varying the nature of the graphic representation used in the task should impact the information processing demands on the decision makers and thus impact group performance [TREI80, TREI82].

The literature cited in this chapter provided a general foundation for this study. More specific ties between the literature and the hypotheses for this research will be identified in the following chapter.

3.0 CONCEPTUAL MODEL, VARIABLE SELECTION, AND RESEARCH HYPOTHESES

The reviewed literature sets the foundation for developing a conceptual model of the research issues to be addressed, for selecting specific variables to study, and for identifying research questions about how the variables are related. The first section of this chapter explains the conceptual model; it is followed by a section providing the rationale for choosing variables. (A discussion of how the variables are operationalized follows in Chapter 4.) The third section of this chapter identifies the research hypotheses.

3.1 Conceptual Model

A visual representation of the conceptual model is presented in Figure 3.1 The decision environment includes the nature of the decision task as well as the physical and social features of the context in which the decision is made. The group decision process, at the heart of the model, entails the set of procedures by which the group operates on the available information to arrive at a decision. Variations in the content, time of presentation, presentation form, and other features of the information available to the group may impact the decision process. The decision process adopted may also be influenced by the presence or absence of a decision strategy suggested by outside sources (management, regulatory agencies, etc.). Decision outcomes include the choices made along with the feelings and perceptions of those involved in making the decision. The model elements are addressed further in the following subsections.

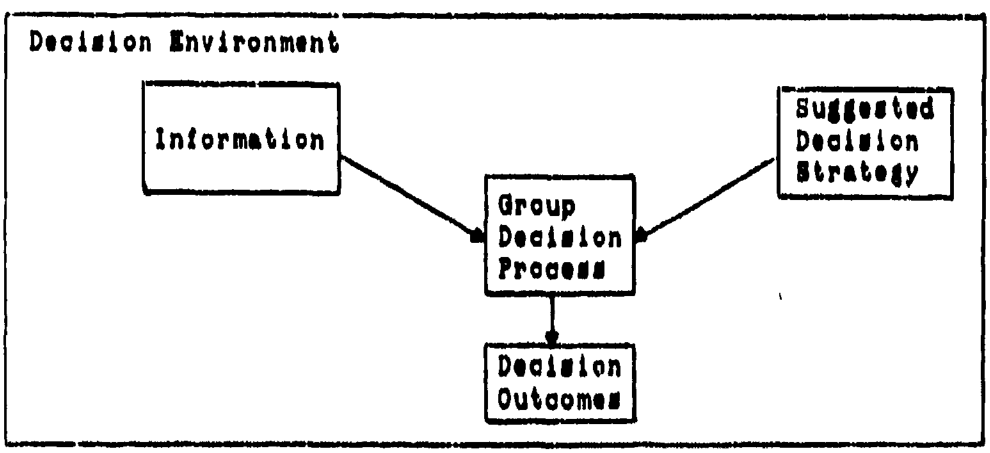

FIGURE 3.1. Conceptual Model

3.1.1 Decision Environment

As indicated in Chapter 2, task differences have had a major influence on research results. The experimental task used in this study was a dynamic intellective task involving uncertainty and various levels of time pressure. All alternatives presented to the decision making group represented potential gains (no risk of loss), some of which were certain and some probabilistic. A detailed description of the task is included in Chapter 4.

The physical features of the decision environment (lighting, seating arrangement, equipment layout, etc.) were controlled. The social context was controlled only to the extent that each group received the same task orientation, had the same opportunity to communicate, and interacted with the same researcher. No attempt was made to constrain the composition of the teams in terms of personality, aptitude, etc.

3.1.2 Group Decision Process

Huber has reviewed several models of group decision behavior which could explain the process of group decision making [HUBE81]. The rational model is based on an assumption that group members use the available information rationally and make their decisions on the basis of the expected utility of the alternatives to the group as a whole. The expectation under a second model, the political/competitive model, is that the group members act as individuals who enter the decision making process with the intent of influencing the group for their own benefit rather than that of the entire group. A third model, the garbage can model, emphasizes chance and timing in the decision making process. It states that decisions occur at the intersections of problems looking for solutions, solutions looking for problems, and decision makers looking for opportunities to make decisions. Finally, the program model holds that decisions are the natural consequences of existing group standards and norms and the background, training, and biases of the group members.

All but the program model were discarded for use in the conceptual model to describe the group decision process. First, as indicated in Chapter 2, decision groups tend not to behave rationally, especially under conditions of uncertainty. Next, since performance was scored only on a team basis, there was nothing obvious to be gained by any individual from a competitive/political approach to the task. Finally, over the course of this study, each team experienced comparable effects of chance and timing on their decision alternatives, so any differences in decision outcomes could not be explained by the garbage can model. The suggested decision strategy used in this study was designed to overcome group member biases (e.g., bias toward certain gains over uncertain gains of equal or higher expected utility) in performing a particular dynamic intellective task. This research attempts to show that the decision processes of teams without the suggested decision strategy may be described using Huber's program model and that use of the suggested strategy changes decision processes by overcoming biases.

3.1.3 Information

Information content, availability, and presentation media were held constant for all groups in this study, but information presentation form varied. A presentation form that places lower demands on the group's information processing capacity than another form should reduce the need for task training. Aiding the identification and location of high value alternatives through appropriate presentation form may also help to overcome some biases. Information presentation form, then, may influence the group decision process and ultimately have an impact on decision outcomes.

3.1.4 Suggested Decision Strategy

. Hackman and Morris propose that the group strategy for carrying out a task (the collective choices made about how the group will proceed) controls a major portion of the variation in group decision performance. A team may either implicitly or explicitly develop its own strategy, which could be either a good or a poor strategy, or it may adopt a strategy developed outside the group (imposed by management, recommended by consultants, etc.) [HACK83]. A suggested decision strategy that is adopted by a group constitutes a direct intervention in the group decision process. If Huber's program model holds, the intervention could affect the decision process by overcoming biases of group members and setting new group norms.

3.1.5 Decision Outcomes

The most obvious outcome of the group decision process is the decision itself. Chervany, Dickson, and Kozar [DICK77] suggest that the effectiveness of the decision process may be measured in terms of decision quality, cost, profit, time, etc. For the dynamic intellective task used in this research, the primary measure of decision effectiveness was a composite of the correctness and timeliness of decisions. Other decision outcomes include developed or revised decision strategies, evolved patterns of communication and influence among the group members, individual perceptions of the task and of other group members, and so on. For this investigation, particular attention was paid to perceptions of the workload imposed by the task.

The elements of the conceptual model and the relevant literature suggest a set of possible research variables. The variables chosen for this study are identified in the next section.

3.2 Experimental Variables

Figure 3.2 categorizes the experimental variables as independent, dependent, or controlled. The variables in each category are addressed in the following subsections.

3.2.1 Independent Variables

Chervany, Dickson, and Kozar identified a set of independent variables that have an impact on decision quality. The independent variables include the decision maker, the decision environment, and the characteristics of the information system used to support the decision process [DICK77, IVES80]. The group decision process itself has also been identified as an important variable often ignored in MIS experimental research [BENB84]. As indicated by the research purpose statement provided in Chapter 2, this study is focused on facilitating decision performance through graphic information presentation and decision heuristics. In other words, the primary independent variables involve the information presentation form (a characteristic of the information system) and a suggested decision strategy (a direct intervention in the group decision process). Two additional variables suggested by the literature were time stress and practice.

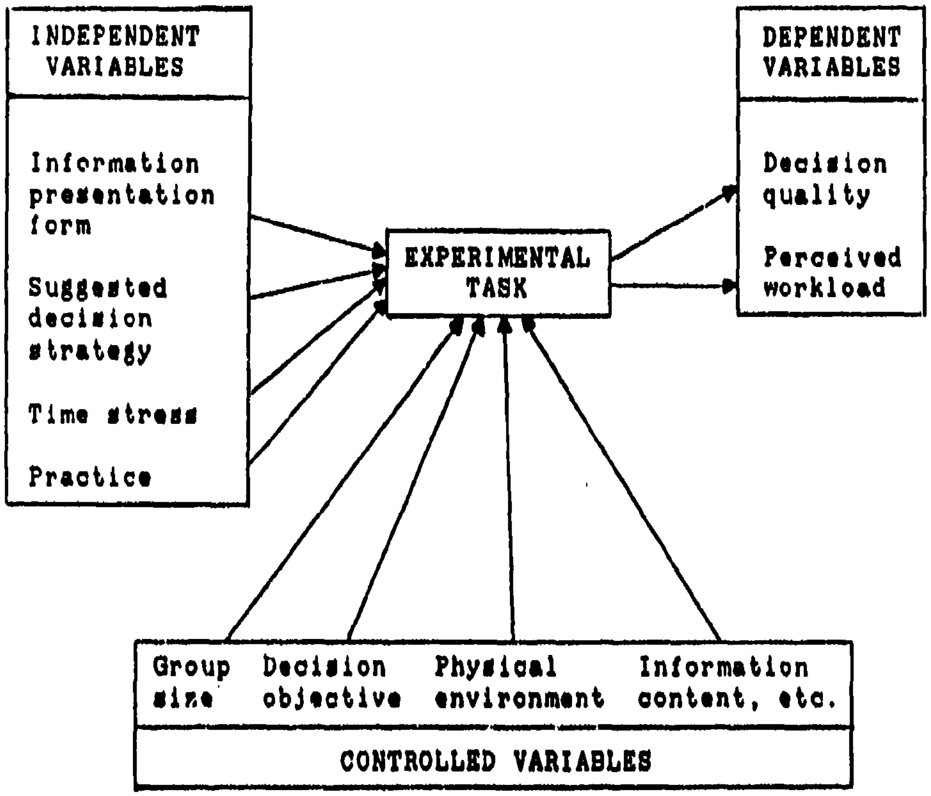

FIGURE 3.2. Experimental Variables

3.2.1.1 Information Presentation Form. Two distinct contrasts relating to information presentation form are addressed in this study. First, based on feature integration theory, single-featured codes are contrasted with codes that use conjunctions of features. Feature integration theory indicates that performance on a visually oriented task involving location and identification of objects varies with the form in which the objects are presented [TREI80]. Specifically, performance using conjunctively coded objects differs from performance using single-featured objects. The second contrast addressed by this study is between two single-featured visual codes. Christ and others have shown that object identification performance varies with differences among single-featured coding schemes [CHRI75, CHRI83, IVES82]. To examine both contrasts in this study, information presentation form was varied between groups, each decision making team receiving information presented via a color (single-featured), an alphabetic (single-featured), or a combined color and alphabetic (conjunctive) coding scheme.

3.2.1.2 Suggested Decision Strategy. For this study, half of the groups were left to develop their own strategy and half were provided with and encouraged to use an experimenter-developed strategy. The suggested strategy took the form of a set of four decision heuristics (see Chapter 4) which should lead to consistently good, although not necessarily optimal, performance on the task.

3.2.1.3 Time Stress. Previous studies using very similar experimental tasks have shown that performance declines under increased levels of time stress [BROW85, WILS87]. Time stress should have the same effect in this study. The real intent in including time stress as a variable, however, is to examine its interaction with the primary independent variables, information presentation form and suggested decision strategy. Are performance differences associated with variations in the primary variables any more or less evident under various task conditions? One mechanism for increasing attention loads (task difficulty) in a visual identification task is to increase the speed at which objects are presented (increase time stress). This study compared performance within groups at two levels of time stress. The rate at which objects were presented in half of the experimental trials was twice as high as in the other half; the sequence of high stress and moderate stress trials was randomized.

3.2.1.4 Practice. According to the Power Law of Practice, mental task performance improves with practice. More specifically, the greatest improvements are achieved in the early stages of learning with performance leveling out over time [CARD83]. Performance on the TRAP, then, should improve with practice, especially in early sessions, as it has in previous related studies [BROW85, WILS87]. Because of the potential effects, there have been calls to include practice or learning as an independent variable in graphics research [JARV86b]. As was the case for the time stress variable, however, the practice variable is included primarily to examine its interactions with the presentation form and decision strategy variables. In this study, each team completed a training session and a total of 32 experimental trials arranged in 4 sessions of 8 trials each. The design provided for a within-group assessment of practice effects over the four experimental sessions.

3.2.2 Dependent Variables

The decision outcomes of interest in this study were decision quality and perceptions of workload. For the dynamic intellective task used in this research, both decision correctness and decision making time were reflected in measures of decision quality. Perceptions of the workload imposed by the task were captured in terms of perceived time stress, mental effort, and psychological stress.

3.2.2.1 Decision Quality. High quality decisions in performing the experimental task depend on both speed and accuracy in identifying and committing resources to high value events. Therefore, performance was measured in terms of efficiency (scores amassed in given amounts of time). Specifically, two types of decision quality scores were examined and compared across treatments: ratios of the average points earned by the teams to the points earned by a "model" decision maker and proportions of various types of events completed.

3.2.2.2 Perceived Workload. Data on perceived workload was collected using the Subjective Workload Assessment Technique (SWAT) (see Appendix A for a description of SWAT). Immediately following each experimental trial, each participant rated the trial in terms of its time stress, its demands on mental effort, and its psychological stress (level of confusion, distraction, etc.). The three ratings were weighted and combined to form an overall measure of perceived workload. Individual SWAT scores were then averaged to generate a group measure of perceived workload; team data was compared across treatments.

3.2.3 Controlled Variables

Some variables that were not chosen as independent variables for this study are known to affect group decision performance. Those variables (group size, the decision objective, the physical features of the task environment, and the information provided to the decision makers) were controlled to minimize their influence on the group decision process.

3.2.3.1 Group Size. Group size was held constant at three individuals per team.

3.2.3.2 Decision Objective. The decision objective (the purpose or goal toward which decision makers direct their decision behavior) is a variable that can influence the decision process [CLARC83]. The decision objective in the experimental task was to maximize total points earned by the team. A statement of the objective was included in the training provided to all participants (see Chapter 4).

3.2.3.3 Physical Environment. The lighting, seating arrangement, and physical layout of the experimental facility was identical for all teams.

3.2.3.4 Information Content, Availability, and Presentation Media. Huber lists the following data requirements for rational decision making [HUBE81]:

-- What are the alternatives?

-- What are the future conditions that might be encountered?

-- What are the probabilities of the future conditions?

-- What are the criteria to be used in evaluating alternatives?

-- What are the relative importances of the various criteria?

-- What are the payoffs, or costs, associated with various outcomes?

-- What are the constraints on the payoffs or costs?

Presentation forms varied, but the content and timing of information to meet each of the requirements was the same for all groups in this study. The experimental task was presented to all teams via individual CRT's. Event sequences were randomized, but the number of events per trial and the mix of event types was constant for every trial and was identical for all teams.

3.3 Research Hypotheses

The preceding section on experimental variables identified information presentation form and decision strategy as the primary independent variables in this research. The plan for the research was to measure the effect of varying those factors on two decision outcomes: decision quality and perceived workload. The following subsections provide sets of hypotheses that anticipate the effects of each of the independent variables and their key interactions on decision quality and perceived workload. The hypotheses in section 3.3.9 address a comparison of the effects of information presentation form and suggested decision strategy on decision quality and perceived workload.

3.3.1 Effects of Information Presentation Form

Experimental comparisons among a variety of information presentation forms are valuable in that the results lead to practical guidelines for system development. This research compares the impact of three coding schemes: two single-featured schemes (color and alphabetic) and a conjunctive scheme (combination of color and alphabetic). A clear advantage for one scheme would lead to recommendations for that scheme in designing systems for team decision making in similar decision environments. If no clear difference among the schemes emerges, system designers have a more open choice. The following two subsections present hypotheses concerning the effects of information presentation form on decision quality and perceived workload.

3.3.1.1 Information Presentation Form and Decision Quality. In tests of a feature-integration theory of attention, performance on visual tasks involving location and identification of objects was altered by changing the features used to distinguish objects in the visual display [TREI80]. The theory suggests that people perform visual search tasks more quickly and accurately when the cues vary on a single dimension rather than as conjunctions of features. The symbols used to represent events in a baseline study using the Team Resource Allocation Problem (TRAP) [BROW85] appeared as conjunctions of separable features (shape and color). If, instead, symbols were to vary within a single feature (e.g., color) teams should be able to recognize events without having to focus attention on each symbol serially. Therefore, they should identify and choose the most beneficial events more readily and achieve higher scores than those teams who must attend to conjunctively coded symbols.

In a review of color coding research, Christ [CHRI75] examined the results of a number of studies that reported data on the accuracy and speed of identifying single-featured stimuli. He concluded that color is superior to size, brightness, and shape but inferior to letters for <u>accuracy</u> in identification tasks. On the other hand, color provided a <u>speed</u> advantage over letters for locating objects in a display. Christ later confirmed that location times were shorter for colored dots than for letters in dense displays (12-object displays as contrasted to 4-object displays) [CHRI83]. Since performance in the TRAP depends on both accuracy and speed in identifying the event symbols, the results reported by Christ provide no clear expectation of an advantage in TRAP performance for either alphabetic or color coding.

The combined expectations for the effects of information presentation form on decision quality based on feature integration theory and the results of previous research with single-featured visual codes may be stated in hypothesis form:

> H1a. The quality of team decisions in the TRAP will be higher for teams confronted with single-featured (either alphabetic or color-coded) event symbols than for teams confronted with events represented by conjunctions of features. However, there will be no difference in decision quality between teams using an alphabetic coding scheme and teams using a color coding scheme.

3.3.1.2 <u>Information Presentation Form and Perceived Workload</u>. Because 'operators tend to adapt to tasks and hold performance constant over a broad range of conditions,' [LEMA86, p. 638] performance measures may not reflect the full impact of the information presentation form treatments. Although performance differences may be minimal or nonexistent, however, the subjects may still perceive differences in mental workload. Subjective measures of mental workload have been shown to be sensitive to objective changes in task workload [LEMA86]. Therefore, they represent alternative and potentially more sensitive measures of the impact of differences in information presentation treatments in the TRAP.

Since subjective workload measures are alternate measures of the same effects rather than measures of different effects, it is assumed that factors that lead to better performance should also lead to perceptions of lower workload. Specifically, since feature integration theory states that people perform visual tasks more quickly and accurately when the cues vary on a single dimension rather than as conjunctions of features, it is reasonable to expect that people using single-featured cues would also perceive lower levels of mental workload. Since color and alphabetic coding schemes seem to trade off speed for accuracy in visual search tasks, no differences in perceived workload are expected between the two single-featured coding schemes. Thus, the following hypothesis concerning perceived workload parallels that concerning team decision quality:

> H1b. The perceived workload in the TRAP will be lower for teams confronted with single-featured (either alphabetic or color-coded) event symbols than for teams confronted with events represented by conjunctions of features. However, there will be no difference in perceived workload between teams using an alphabetic coding scheme and teams using a color coding scheme.

3.3.2 <u>Effects of Suggested Decision Strategy</u>

Debiasing methods (techniques for reducing human bias in decision making) include providing training for the decision task [FISC82]. Providing decision-aid heuristics as a form of task training has been shown to improve decision performance on an ill-structured career planning task [CATS87]. As an intellective task, the TRAP is a task with demonstrably correct choices [MCGR84]. Prescriptive heuristics for the TRAP were developed to overcome specific biases evident in the performance of previous participants in the TRAP (see Chapter 4); i.e., the heuristics lead the decision makers to recognise the demonstrably correct choices. The following two subsections present hypotheses concerning the effects of a suggested decision strategy in the form of decision-aid heuristics on decision quality and perceived workload.

3.3.2.1 <u>Suggested Decision Strategy and Decision Quality</u>. It has been shown that, for intellective tasks, the best-fitting model of a decision rule is 'truth supported wins' (if at least two group members recognize the right answer, the group will accept it as correct) [MCGR84]. Providing decision heuristics should increase the probability that at least two group members will recognize the correct choices in the TRAP and should lead to improved decision performance.

An indirect benefit of providing decision heuristics follows from the explicit attention paid to a decision strategy. Hackman and Morris propose that the strategy (the collective choices made about how the group will proceed) used by group members in carrying out the task is a variable that controls a major portion of the variation in group decision performance. There seems to be a pervasive norm, however, against explicitly discussing the group strategy in spite of the fact that group performance seems to improve with explicit attention to the strategy [HACK83]. Providing a set of decision heuristics to a decision making group and encouraging a discussion about the heuristics should, therefore, lead to improved decision performance.

> H2a(1). The quality of team decisions in the TRAP will be higher with provision and discussion of decision heuristics than without provision and discussion of decision heuristics.

A particular aspect of decision quality of special interest to this study is the quality of decisions made under uncertainty. (Note that this aspect of decision quality was not addressed in the discussion about the effects of information presentation form. Since uncertain events in the experimental task are presented to all decision teams in identical formats (see chapter 4), there should be no presentation impact on decisions about uncertain events.)

Expected utility theory states that rational decision makers, given the possible payoffs of the alternatives and the probabilities of various states of nature, choose among alternatives on the basis of expected utility (the product of the probability of an outcome and its potential utility) [KAHN79]. In a number of studies, however, decision makers have tended to favor certain outcomes over merely probable outcomes with equivalent or even higher expected value (an aspect of prospect theory) [KAHN79]. Prospect theory, then, would suggest that teams would undervalue uncertain events in the TRAP. The 'choice shift' phenomenon in groups, the tendency for groups to gamble more or less than their individual members would in making the same decision [FISH80, MUHS81], suggests that teams could either undervalue or overvalue uncertain events in the TRAP. The direction of difference, therefore, is difficult to predict. In the absence of provision and discussion of decision heuristics, however, teams should seek additional information about and then commit resources to uncertain events in the TRAP at a rate different from that anticipated under expected utility theory. Since the heuristics provided as a suggested decision strategy are based in part on expected utility theory, however, teams receiving and discussing the heuristics should choose to commit resources to uncertain events according to expected utility theory.

> H2a(2). Without the provision and discussion of decision heuristics, teams will seek additional information about and commit resources to uncertain events at a rate different from that anticipated according to expected utility theory. With the provision and discussion of decision heuristics, teams will seek additional information about and commit resources to uncertain events according to expected utility theory.

3.3.2.2 Suggested Decision Strategy and Perceived Workload. Since the suggested decision strategy is expected to increase the probability that at least two group members will recognize the correct choices and since the group will know that they share a common strategy, teams receiving the heuristics should perceive a lower level of workload in the TRAP.

> H2b. The perceived workload in the TRAP will be lower with provision and discussion of decision heuristics than without provision and discussion of decision heuristics.

3.3.3 Effects of Time Stress

Among the dimensions on which a decision task can vary are task content, task difficulty, and task structure [DICK86]. For this research, common task content and task structure were maintained for all participants in all sessions. In order to detect some of the influence of the task environment on performance, task difficulty was varied. One mechanism for increasing task difficulty in a visualidentification task is to increase the speed at which objects are presented (increase time stress).

3.3.3.1 Time Stress and Decision Quality. Previous studies using very similar experimental tasks have shown that performance declines under increased levels of time stress [BROW85, WILS87]. Time stress should have the same effect in this study.

> H3a. The quality of team decisions in the TRAP will be higher under moderate time pressure than under high time pressure.

3.3.3.2 Time Stress and Perceived Workload. Particularly since one of the three components of the workload measure used focuses on time stress, perceptions of workload in the TRAP should increase under increased time stress.

H3b. The perceived workload in the TRAP will be lower under moderate time pressure than under high time pressure.

3.3.4 Effects of Practice

Because of the potential effects of learning on task performance in tasks using graphic representations, there have been calls to examine practice or learning effects in graphics research [JARV86b]. Participants in this study completed a total of 32 experimental trials, providing opportunity to detect the impact of learning on performance.

3.3.4.1 Practice and Decision Quality. According to the Power Law of Practice, mental task performance improves with practice. More specifically, the greatest improvements are achieved in the early stages of learning with performance leveling out over time [CARD83]. Performance on the TRAP, then, should improve with practice, especially in early sessions, as it has in previous related studies [BROW85, WILS87].

H4a. The quality of team decisions in the TRAP will improve with practice, especially in early sessions.

3.3.4.2 Practice and Perceived Workload. With practice, decisions in the TRAP should become relatively routine. Perceptions of workload, then, should decrease at a decreasing rate.

H4b. The perceived workload in the TRAP will decline with practice, especially in early sessions.

3.3.5 Interactive Effects of Time Stress and Information Presentation Form

One primary interest in examining the effects of time stress in this research concerns the interactive effects of time stress and information presentation form. The impact of information presentation form could vary depending on task difficulty, operationalized in this study as time stress.

3.3.5.1 Time Stress/Information Presentation Form and Decision Quality. Since time pressure would constrain the time available to focus on individual symbols, teams that can recognize symbols in parallel should have an increasing advantage as time pressure increases over teams that must attend to symbols serially. Treisman and Gelade also report that operating with conjunctively coded objects under time constraints leads to false positive errors (illusory conjunctions) [TREI80]. Therefore, the advantage of single-featured symbols over conjunctively coded symbols should be more pronounced when time pressure increases.

Christ [CHRI75] concluded that the relative effectiveness of single-featured (color and alphanumeric) symbols for accuracy in identification tasks varied with task difficulty. For example, the accuracy advantage for alphanumeric symbols increases with increases in the number of stimuli to be identified and with decreases in exposure time. The speed advantage for locating colors over locating letters, however, should also be more intense under high time pressure. Since there are offsetting forces associated with time pressure, it is reasonable to expect that the relative effectiveness of alphabetically coded symbols and color coded symbols in the TRAP should not vary with increased time pressure.

> H5a. Time pressure and presentation treatment will interact such that the advantage of single-featured coding over conjunctive coding for decision quality will be greater under high time pressure than under moderate time pressure. However, the relative effectiveness of alphabetic and color coding for decision quality will remain the same whether under high or moderate time pressure.

3.3.5.2 Time Stress/Information Presentation Form and Perceived Workload. The strain of attempting to serially attend to each symbol under increased time pressure should affect the workload perceptions of teams using conjunctively coded symbols. Therefore, the advantage of single-featured symbols over conjunctively coded symbols should be more pronounced when time pressure increases. Offsetting forces relating time pressure to single-featured codes, however, lead to an expectation that any differences in workload perceptions between teams using alphabetically coded symbols and teams using color coded symbols will not vary with increased time pressure.

> H5b. Time pressure and presentation treatment will interact such that the advantage of single-featured coding over conjunctive coding for perceived workload will be greater under high time pressure than under moderate time pressure. However, the relative impact of alphabetic and color coding on perceived workload will remain the same whether under high or moderate time pressure.

3.3.6 Interactive Effects of Practice and Information Presentation Form

As was the case for time stress, a primary interest in examining the effects of practice in this research concerns the interactive effects of practice and information presentation form. Practice could mediate the impact of information presentation form on performance and perceived workload.

3.3.6.1 Practice/Information Presentation Form and Decision Quality. Because other researchers had found qualitative changes in performance on visual tasks with extended practice, Treisman and Gelade examined the effects of practice on searching for conjunctively coded objects. They found no indication of movement from serial to parallel processing over 13 blocks of practice [TREI80]. Therefore, performance differences between conjunctive and single-featured coding schemes should remain constant even with extended practice.

On the other hand, Christ has demonstrated that extended practice with a visual task tends to attenuate any differences in performance based on use of different single-featured codes (letters, digits, familiar geometric shapes, and colored dots) [CHRI75, CHRI83]. In other words, although no overall difference in performance has been hypothesized between the alphabetic and color coding schemes, any differences that might exist during early experimental sessions would be attenuated with practice.

> H6a. Practice and presentation treatment will interact such that any differences in the relative effectiveness of alphabetic and color coding for decision quality will attenuate over the four experimental sessions. However, differences in the relative effectiveness of conjunctive and single-featured coding will remain constant over the four experimental sessions.

3.3.6.2 Practice/Information Presentation Form and Perceived Workload. If the mechanism by which people must identify conjunctively coded symbols (serially attending to each symbol) does not vary with practice, it is likely that differences in workload perceptions between those using conjunctive and those using single-featured schemes will not vary with practice. On the other hand, practice should make users equally comfortable with any single-featured coding scheme, attenuating any early differences.

H6b. Practice and presentation treatment will interact such that any differences in perceived workload associated with alphabetic and color coding will attenuate over the four experimental sessions. However, differences in perceived workload associated with conjunctive and single-featured coding will remain constant over the four experimental sessions.

3.3.7 Interactive Effects of Time Stress and Suggested Decision Strategy

Time stress, as a component of task difficulty, is expected to interact not only with information presentation form but with the suggested decision strategy. The impact of the suggested decision strategy could vary depending on the level of time stress.

3.3.7.1 Time Stress/Suggested Decision Strategy and Decision Quality. The provision and discussion of heuristics should routinize some decisions or establish an efficient process for making decisions. Therefore, heuristics should be even more beneficial under high time stress than under moderate time stress.

H7a. Time pressure and heuristics treatment will interact such that the difference in decision quality related to heuristics treatment will be greater under high time pressure than under moderate time pressure.

3.3.7.2 Time Stress/Suggested Decision Strategy and Perceived Workload. Assuming that the heuristics provided are simple and limited in scope so as not to induce stress themselves, routinizing decisions through provision and discussion of heuristics should reduce workload perceptions even more under high time stress than under moderate time stress.

H7b. Time pressure and heuristics treatment will interact such that the difference in perceived workload related to heuristics treatment will be greater under high time pressure than under moderate time pressure.

3.3.8 Interactive Effects of Practice and Suggested Decision Strategy

Along with examining the mediating effects of practice on the impact of information presentation form, this study addresses the interactive effects of practice and the suggested decision strategy.

3.3.8.1 Practice/Suggested Decision Strategy and Decision Quality. Extended practice with the TRAP should allow teams to discover and adopt on their own strategies that approximate the benefits of the suggested decision strategy. If so, performance differences between teams operating with and those operating without the suggested decision strategy would attenuate with practice.

> H8a. Practice and the suggested decision strategy will interact such that the advantage with provision and discussion of decision heuristics will attenuate over the four experimental sessions.

3.3.8.2 Practice/Suggested Decision Strategy and Perceived Workload. As teams without the suggested decision strategy discover and adopt strategies that routinize decision-making, their perceptions of workload should approach those for teams with the suggested decision strategy.

> H8b. Practice and the suggested decision strategy will interact such that differences in perceived workload between teams with and those without provision and discussion of decision heuristics will attenuate over the four experimental sessions.

3.3.9 Relative Effects of Information Presentation Form and Suggested Decision Strategy

While there have been studies about the effects of various presentation forms and others about the effects of suggested heuristics, there is very little research evidence concerning the relative impact of presentation form and heuristics. Cats-Baril and Huber examined the effects of decision-aid heuristics on decision quality in an ill-structured career planning task. In their study, use of a heuristic had a positive impact on decision quality, but computer delivery of decision aids, as opposed to pencil-and-paper delivery, had no effect [CATS87]. Given the limited theoretical and research basis for prediction, the hypotheses addressing relative impact are stated here in the null form.

3.3.9.1 Information Presentation Form vs Suggested Decision Strategy and Decision Quality.

> H9a. The magnitude of impact on decision quality related to information presentation form and to the suggested decision strategy will be the same.

3.3.9.2 Information Presentation Form vs Suggested Decision Strategy and Perceived Workload.

> H9b. The magnitude of impact on perceived workload related to information presentation form and to the suggested decision strategy will be the same.

3.4 Summary of Hypotheses

The hypotheses for this research predict that information presentation form, suggested decision strategy, time pressure, and practice each have an impact on both decision quality and perceived workload in a dynamic group decision task involving uncertainty. The two primary independent variables, information presentation form and suggested decision strategy, are hypothesized to have equal impact on decision quality and perceived workload. Time stress and practice are hypothesized to have a modifying influence on the effects of information presentation form and suggested decision strategy. The next chapter explains the context in which the hypotheses were tested by describing the experimental task and the procedures followed in conducting the research.

4.0 RESEARCH ENVIRONMENT AND METHOD

Because of the importance of task variables in experimental research, the first section of this chapter is devoted to a description of the experimental task used in this study, the Team Resource Allocation Problem (TRAP). The second section outlines the methods followed in carrying out the study.

4.1 Experimental Task

This research is part of a series of experiments conducted at the Harry G. Armstrong Aerospace Medical Research Laboratory (AAMRL) at Wright-Patterson Air Force Base, Ohio, under the overall title, 'The Use of Team Technologies to Enhance Multi-Human Decision Making.' The purpose of the research program is to understand the variables that influence small group decision making in an Air Force command and control setting. Command and control decision making, which is closely related to performance review and monitoring, is among the tasks for which empirical research concerning the usefulness of graphic displays is most lacking [JARV86b]. The series of experiments at AAMRL uses variations of a dynamic group choice task called the Team Resource Allocation Problem (TRAP).

4.1.1 Team Resource Allocation Problem (TRAP)

The TRAP was designed to simulate both the individual cognitive processes and the small group interaction processes involved in making command and control decisions. It was derived from the task used by Pattipati, Kleinman, and Ephrath [PATT83] to study dynamic individual decision making. The TRAP is intended to be a general problem, adaptable to a variety of research objectives.

In its current form, the TRAP is designed for three-person teams who are seated side-by-side and allowed to communicate freely. Figure 4.1 depicts the seating arrangement. Each team member has a four-button control box, which is illustrated in Figure 4.2. Identical TRAP displays are presented simultaneously to each team member via Silicon Graphics 2400 RGB high-resolution computer graphics work stations. Figure 4.3 portrays a TRAP display at a discrete point in time as it might appear using the alphabetic treatment.

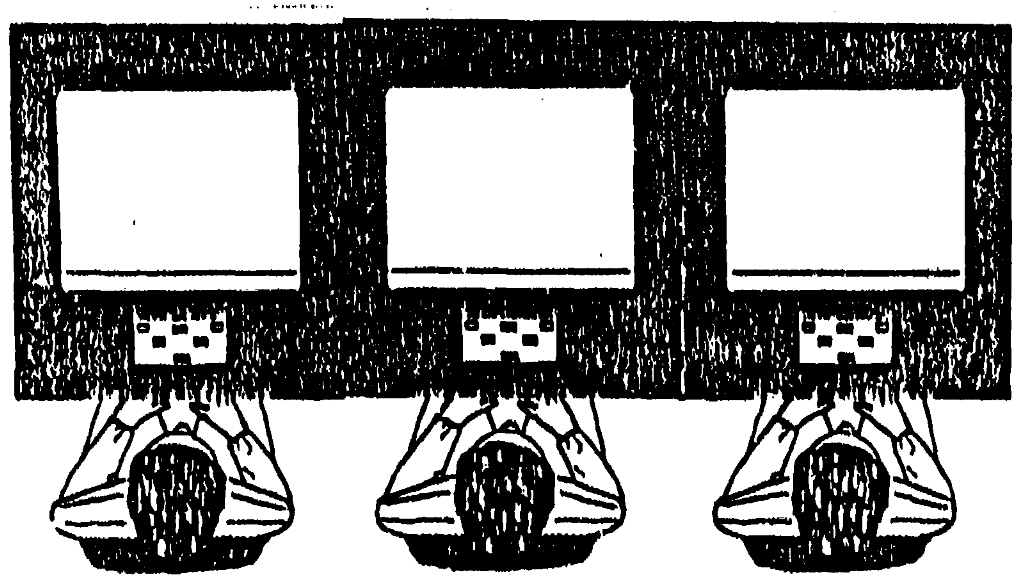

FIGURE 4.1. Seating Arrangement

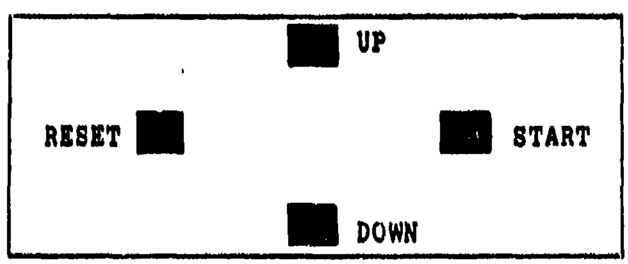

FIGURE 4.2. Control Box

4.1.2 <u>TRAP Events</u>

As many as 11 events may be portrayed at a time, each appearing on a separate row in the TRAP display. A team earns points by committing its resources to an event or events for the required period of time. As briefed to each team during a training session (see Appendix B), their objective for the TRAP is

> to accumulate as many points as possible <u>as a team</u>. This means discussing alternatives with the other members of the team in order to make optimum selection of events. As there

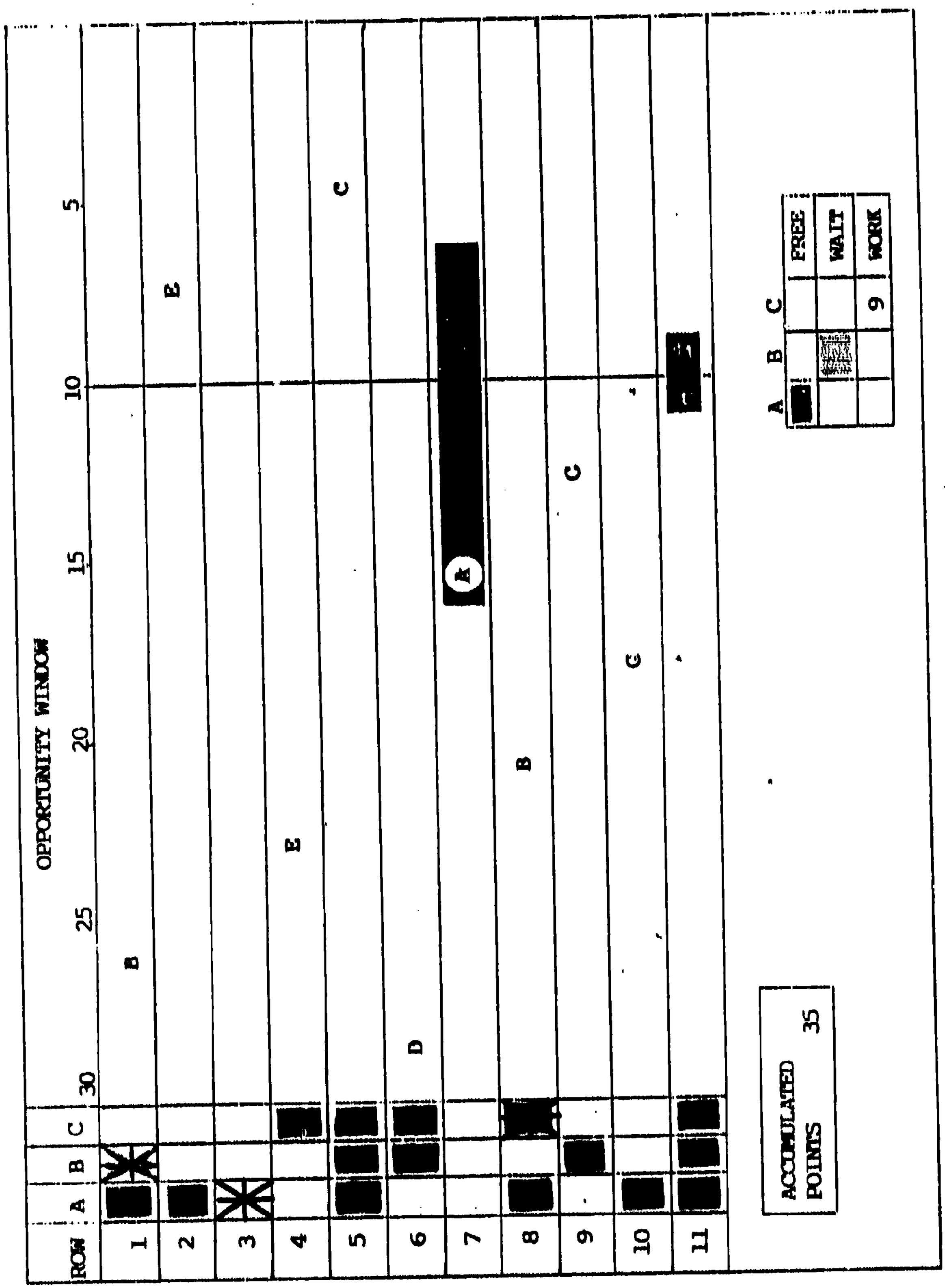

Figure 4.3 TRAP Display

will be more events than the team can possibly process, combinations of events should be selected which optimize team performance and total point count.

Events are represented symbolically on the TRAP display. Each new event is assigned randomly to an available row in the display; its symbol appears initially just to the right of column C in its assigned row. The event symbols move across the display at a common, steady rate until they disappear from the right side of the screen.

4.1.2.1 <u>TRAP Event Timing</u>. An event symbol appears on the display for a total of 30 time units, and teams are required to commit resources to an event for 10 time units to earn its points. Under the high time stress condition a time unit is 1 second with a new event symbol appearing every 2.72 seconds; under the moderate time stress condition a time unit is 2 seconds with a new event symbol appearing every 5.45 seconds. Pilot studies revealed that a 2-second time unit allows good teams to approach maximum scores; scores are significantly lower with a 1-second time unit. The rates at which new events appear provide for the possibility of displaying an event on each of the 11 rows at the same time (e.g., 30 time units/11 rows = 2.72 seconds between events).

Each TRAP trial under the high time stress condition is approximately 4 minutes long; trials under moderate time stress take approximately 8 minutes each. Teams have to make their decisions more quickly under the high time stress condition; events appear at a faster rate and move across the display more quickly. However, equivalent scores are possible under either time stress condition. The number of events presented (44 certain events and 20 uncertain events) and the mix of point values available in a trial are the same under both conditions. Because the amount of time that team members are required to commit resources to an event is proportional to the duration of a time unit, teams can theoretically complete the same number of events and earn the same scores under both levels of time stress.

4.1.2.2 <u>TRAP Event Types</u>. Two types of events are represented in the TRAP: certain and uncertain events. Certain events are represented as circles and uncertain events as black rectangles. The payoff for committing resources to certain events is known and guaranteed. The payoff for committing resources to uncertain events is initially unknown and, once known, is not guaranteed. (A specified probability exists that no points will be earned for committing resources to uncertain events.)

4.1.2.2.1 <u>Certain Events</u>. Table 4.1 identifies the possible point values for certain events and the frequency with which each event value appears in a TRAP trial. A TRAP trial presents a total of 44 certain events, distributed such that each team member has an equal opportunity to participate in events of a given value. For example, the six 1-point-per-person, one-person events in each trial are assigned as two for each team member. A small set of events of randomly selected values is also presented at the beginning and end of each trial; performance on these buffer events is not analyzed.

TABLE 4.1. Point Values for Certain Events

	Points Per Person	Total Points	Frequency
One-Person Events	1	1	6
	3	3	12
	5	5	6
Two-Person Events	2	4	6
	4	8	6
Three-Person Events	1	3	2
	3	9	4
	5	15	2

4.1.2.2.2 <u>Uncertain Events</u>. Mixed among the 44 certain events presented to the participants are 20 events of initially unknown value (some 'black boxes' among the coded circles). When a black box appears, participants may get additional, though imperfect, information about the event if all three team members commit their resources to seeking information. Following that commitment and a brief time delay (two time units), the probability of payoff, 'H'igh or 'L'ow, and the number of points possible for completing the event appear in reverse video on the black box (see Figure 4.3, Row 11). The team may then choose to commit or not to commit resources to the event as with any other event.

During the training session on TRAP with uncertain events (see Appendix C), participants learn that

a. the probability that committing resources to an uncertain event will pay off is either high (80 percent) or low (20 percent)

b. two possible point values (9 and 21) are associated with events having a high probability of payoff and two possible point values (36 and 84) are associated with events having a low probability of payoff

c. each of the four possible types of uncertain events (H9, H21, L36, L84) is equally likely to occur, and

d. considering the payoff probabilities and the time delay to seek information, the uncertain events are, on average, about equivalent to 10-point, three-person events (3 1/3 points per person).

The payoff probabilities and point values used were chosen such that an optimum strategy would include two features:

a. seeking information about a majority of the black boxes and

b. committing resources to about half of the uncertain events for which additional information is obtained (those for which the expected value exceeds the value of other events available on the display).

Scoring for the uncertain events varies from that for other events. A team that commits resources to an uncertain event expects to receive all or none of the possible points for the event, depending on whether or not the event pays off. Therefore, scores displayed to the team reflect award of all or none of the possible points. Of the five H9 events available in a trial, for example, one is randomly selected in advance to pay no points should the team commit resources to that event.

The researcher, however, is interested in comparing the quality of the decision making rather than degrees of luck among the teams. Scores could be distorted, for example, if a team randomly received a large number of points for committing resources to a few low probability events or if a team fails to gain any points despite committing resources to a number of high probability events. Therefore, separate scores are computed for research purposes which add the expected value (the probability of payoff times the possible point value) of each completed uncertain event to the accumulated points for the certain events. Teams should elect to commit resources to uncertain events only when the events' expected values exceed the values of other events on the display. Therefore, scores based on expected values more accurately represent decision making quality.

4.1.2.3 Committing Resources to TRAP Events. Some events may be handled by an individual team member; handling other events may require a specified set of two or all three team members to commit their resources. The black squares in columns A, B, and C in the TRAP display indicate which team members must commit resources to an event to earn its points. The black square(s) appear on a given row at the same time that an event symbol appears on that row and remain on the display as long as the event symbol remains. On the display depicted in Figure 4.3, team member A can handle the event on row 2 individually (a black square appears in column A of row 2), but both team members A and C would be required to commit resources to the event on row 8. No black squares appear on row 3 since no event is available on that row.

Each team member controls a separate cursor which can be moved up or down (using the up and down buttons on the control box) to any row in the member's column on the display. The cursor (an asterisk) is green when the team member is available to commit resources to an event (see Figure 4.3, Column A, Row 3). A team member commits resources to an event by pressing the start button on the control box while the cursor is on the row of a chosen event, at which point the cursor turns red (see Figure 4.3, Column B, Row 1). If additional members are required to commit resources to the same event, the black square in the first member's column turns pink indicating 'waiting' status (see Figure 4.3, Column B, Row 1). The cursors, even while they are red, may be moved to other rows in preparation for other events (e.g., team member C has moved the cursor from Row 7 to Row 8 in Figure 4.3). The start button will not work, however, until the previous commitment is complete. A member may abort a commitment to an event by pressing the reset button on the control box.

4.1.2.3.1 Opportunity Window. In order to commit resources to an event for a full 10 time units before the event leaves the screen, a team must start the event before it reaches the end of the opportunity window. The end of the window is indicated by a vertical line placed such that events reaching the line will remain on the display for 10 additional time units (see Figure 4.3). If a team has not started an event by the time it reaches the end of the window, the team won't be able to commit resources to the event for a sufficient amount of time and won't be able to earn any points for that event.

When all required members have committed resources to an event, the black square(s) turn yellow (see Figure 4.3, Column C, Row 7). In addition, a horizontal black bar appears in that event's row (see Figure 4.3, Row7). The bar starts where the event symbol was when all required resources were committed. It extends to the right for the distance the event symbol will move in 10 time units, the resource commitment time required to earn points for the event. The bar remains stationary, and the event symbol moves through the bar. When the event symbol moves out of the bar, points for completing the event are automatically added to the accumulated points table in the lower left corner of the display, and the cursors for team members whose resources were committed to the event turn green. At the same time, the event symbol, the yellow squares in columns A, B, and C on the same row, and the black bar disappear.

4.1.2.3.2 Resource Status. The table in the lower right portion of the display (see Figure 4.3) provides details on the status of team member resources. A black square in the 'Free' row indicates that a team member's resources are available (see Column A of the table in Figure 4.3). A blinking pink square in the 'Wait' row indicates that a team member's resources are committed but nonproductive until other member(s) commit resources to the same event (see Column B of the table in Figure 4.3). A digit in the 'Work' row indicates the number of time units remaining before a team member's resources will be freed from a current commitment (see Column C of the table in Figure 4.3).

4.1.2.3.3 'Model' Resource Commitment. A computer model that uses 'correct' logic in performing the TRAP has been developed as a basis for comparison with performance by human teams. The computer model compares the values of all alternatives and commits resources to the highest value event or combination of events available at a point in time. It repeats its assessment and resource commitment cycle each time its resources are freed throughout a trial. (Note that the model suboptimizes on the events available at a given point in time rather than optimizing over an entire trial.)

For research purposes, overall team scores are stated as ratios of the points earned by the team to the points amassed by the model. Team scores reflecting proportions of each event type completed are also compared to model results. Relating team scores to 'best possible' scores helps to alleviate any bias associated with variations in the difficulty of the experimental trials (trial difficulty varies due to the randomized sequencing of events).

4.1.3 Presentation Treatments

One objective of this research was to examine the effects of different information presentation forms on group decision quality and perceived individual workload. That objective was met by measuring the impact of variations in the features used to represent certain events. This subsection explains the presentation treatments used.

Recent research on Group Decision Support System design suggests that group performance should be enhanced when features of the group decision support system match the requirements of the decision task [DESA86]. For intellective tasks such as TRAP, DeSanctis and Gallupe suggest that the Group Decision Support System should provide assistance in identifying the correct alternative [DESA86]. Features used to represent events in the TRAP, therefore, should aid in identifying the most beneficial events.

This research examined a set of presentation features to determine which best support identifying high-value TRAP events. Three alternative forms of the TRAP have been developed to allow between-group comparisons among presentation treatments, each using a different event coding scheme. The three presentation treatments use either a single-featured coding scheme (a color scheme or an alphabetic scheme) or a conjunctive scheme. The conjunctive scheme combines the color and alphabetic schemes.

Table 4.2 presents the coding schemes used in the study. In the color scheme, events appear as color-filled circles; in the alphabetic scheme, events appear as yellow-filled circles with black capital letters centered within the circles; in the conjunctive scheme, events appear as red- or blue-filled circles with black capital letters. Table 4.3 illustrates how each of the possible point values is represented in TRAP event symbols.

TABLE 4.2. Coding Schemes for TRAP

	(Points per Person)				
	1	2	3	4	5
Conjunctive	blue C	blue B	blue A	red B	red A
Color	blue	green	yellow	orange	red
Alphabetic	E	D	C	B	A

The color scheme used fits with established guidelines for color displays. The number of colors used is limited [DAVI83, IVES82], and the colors are ordered by their appearance in the rainbow [IVES82]. The ordering also conforms to 'well-established habits or population stereotypes' [DAVI83, p. 118] in that red is used to identify the most important (highest value) events. There is also empirical precedence for the color scheme used; Christ used a six-level color code (purple, blue, green, yellow, orange, and red) in his studies [CHRI83].

The alphabetic scheme used differs from the set used by Christ; he used the letters C, H, K, N, P, and S to minimize confusability among the shapes of the letters [CHRI83]. The ordered set (A, B, C, D, E) was chosen instead to conform to population stereotypes. Since the participants were college students familiar with letters as course grades, A was chosen to represent the highest value events.

TABLE 4.3. Event Symbols for Certain Events

	Color	Alphabetic	Conjunctive	Points Per Person	Total Points
One-Person Events	blue	E	blue C	1	1
	yellow	C	blue A	3	3
	red	A	red A	5	5
Two-Person Events	green	D	blue B	2	4
	orange	B	red B	4	8
Three-Person Events	blue	E	blue C	1	3
	yellow	C	blue A	3	9
	red	A	red A	5	15

The conjunctive code used is a simple combination of the color and alphabetic codes. Red and blue were chosen from the color scheme for their distinctiveness, and A, B, and C were chosen to maintain the sense of ordering established in the alphabetic scheme. Six color-letter combinations are possible in this conjunctive scheme; the red-C combination was arbitrarily dropped to provide the required five-level coding scheme.

4.1.4 <u>Heuristics Treatment</u>

In addition to examining the effects of different information presentation forms on team performance, an objective of this research was to determine if task performance could be improved by providing and encouraging discussion of decision heuristics. Between-group comparisons were made to detect performance differences with and without the provision and discussion of decision heuristics. This subsection provides details concerning the heuristics treatment.

4.1.4.1 Basis for Heuristics. The decision heuristics were built based on information gained from three sources: the computer model against which team performance is compared, the researchers who developed the TRAP, and participants in TRAP pilot studies.

Comparing the choices made by participants in a pilot study to those made by the computer model over a series of 32 trials suggested several heuristics. For example, pilot study participants tended to work significantly fewer high value two-person events than the model did, suggesting that a heuristic to look for such events would be useful. The model also rarely works on the lowest value events, so a heuristic to ignore such events was included.

The TRAP developers also provided decision rules based on their knowledge of task design features and on their repeated observations of teams performing the TRAP. For example, they suggested the decision rule, 'Keep the team synchronized; all three team members should commit their resources to events at the same time.' Their suggestion comes from observations that teams sometimes waste time or miss opportunities to complete high value two- or three-person events while waiting for individual team members to release previously committed resources. Since the amount of time for which resources must be committed is identical for all events, teams that commit their resources in unison will also have their resources free for a subsequent commitment all at the same time.

Finally, participants in a pilot study indicated through their task performance and through their responses to questionnaires and interviews that teams vary significantly in their handling of uncertain events. In particular, their strategies rarely include using expected value to guide decisions about uncertain events. Since using expected value can improve performance on the TRAP, a heuristic based on the expected value of the uncertain events was included. Additional pilot testing also provided performance data and interview material used to fine tune the wording and sequencing of the chosen heuristics.

4.1.4.2 Chosen Heuristics. The set of decision rules chosen represents a balance between comprehensiveness and retainability. The set is comprehensive enough to improve performance but limited enough to avoid overloading human information processing capacity. Teams included in the heuristics treatment received an introduction to the heuristics and their rationale and were encouraged to discuss the heuristics during a training session (see Appendix D.) Stated in terms appropriate to the alphabetic treatment, the decision heuristics used are as follows:

HEURISTIC #1: In addition to 3-person A events, look for a 2-person B event, especially with a 1-person A event.

HEURISTIC #2: Next, check as many uncertain events as you can. Immediately take L84 or H21; ignore L36 and H9.

HEURISTIC #3: Ignore D and E events.

HEURISTIC #4: Keep the team synchronized. All three team members should start an event or combination of events at the same time.

4.2 Research Procedure

In describing the TRAP, the previous section introduced some of the procedures used to carry out this research. This section presents the research procedure in greater detail.

4.2.1 Participants

The participants in the experiment were 72 college students in the Dayton, Ohio area. They were recruited, scheduled, and paid $50 each by Systems Research Laboratories, Inc., an agency that contracted to provide support for research programs at Wright-Patterson Air Force Base. All had at least 20/40 corrected vision (20/70 vision is adequate to perform the TRAP). The participants were also screened for normal color vision using Ishihara plates. Three individuals whose initial screening suggested color vision limitations were assigned to the alphabetic treatment and then underwent additional screening during the training session to assure that they could properly distinguish features on the TRAP display. In addition, no participants who were involved in previous TRAP studies were eligible to participate again.

No restrictions were placed on team composition. Participants were assigned to teams based on their availability (class and work schedules, transportation, etc.). Eight teams were assigned randomly to each of the presentation treatment groups. Among each of the 8-team groups, half were randomly assigned to each of the decision strategy treatments.

4.2.2 Experimental Procedure

The experiment was conducted in an established experimental facility within the Armstrong Aeromedical Research Laboratory, Wright-Patterson Air Force Base, Ohio. Teams consisted of three participants each who were seated side by side (positions were randomly assigned). Each participant had a CRT and a control box for performing the TRAP. Participants wore headsets with lip microphones for recording team communication.

Each team participated in four sessions, each conducted on a separate day. The first session covered administrative requirements (consent forms, visual screening, and the first data collection phase of the Subjective Workload Assessment Technique (see Appendix A)). Participants were trained during the second session, and the experimental trials were run during the last two sessions.

Because the TRAP is very complex, training and practice prior to experimental participation is required. A training session of approximately two hours familiarized participants with the TRAP, first without uncertain events and then with uncertain events. Each team was trained using versions of the TRAP appropriate to the presentation treatment group to which the team was assigned. Those teams assigned to the heuristics treatment groups received instruction on the heuristics immediately following training on the TRAP with uncertain events and were allowed time to discuss their decision strategy. They were also allowed to retain printed copies of the heuristics for use in the test sessions. Participants were tested during the training session to assure that they understood how event point values were determined and, for those teams who received heuristics, that they understood how to apply the heuristics. Each team also completed two practice trials without uncertain events and an additional four practice trials with uncertain events with free opportunity to ask questions and to communicate with one another.

Following the training session, each team completed two experimental sessions, scheduled on separate days. Each experimental session consisted of two test sessions, and each test session consisted of eight trials. At the end of each trial, the participants provided data for phase two of the Subjective Workload Assessment Technique (see Appendix A). All experimental sessions were audio/videotaped, and tapes of the best three and poorest three teams (based on average decision quality scores) were reviewed to determine the extent to which teams discussed their task performance strategies and explicitly applied the decision heuristics. The analysis of the tapes provided subjective explanatory material rather than statistically analyzed results. It helped to identify differences among the team in applying the heuristics as well as differences among the suggested heuristics in their rates of application. It also helped to detect whether teams that did not receive suggested heuristics developed similar or alternate heuristics of their own.

In greater detail, the experimental procedure consisted of the following steps (copies of materials used for the color coding scheme in the experiment are included as appendices; equivalent materials were used for other treatment groups):

1. First session (approximately one hour): Screened participants and administered preliminary materials.

    a. Researchers in the Visual Display Systems Branch, Armstrong Laboratory, administered color vision screening using Ishihara plates under the prescribed lighting conditions. The experimenter administered visual acuity screening using Snellen charts (participants were screened for 20/40 corrected vision; the TRAP display required 20/70 vision).

    b. Participants read and signed two consent forms (Appendix E). The forms introduced the research objectives and outlined the terms of the participants' agreement to serve as team members for the experiment. Copies of the forms were made available to the participants.

    c. The experimenter introduced the Subjective Workload Assessment Technique using a standard script (Appendix F) and provided card decks and SWAT summary handouts for use during the sorting procedure. Participants completed the SWAT sorting procedure. (SWAT sort data has been shown to be stable for as long as a year [HARR87], so participants for whom recent SWAT sort data was available were not required to repeat the sorting procedure.)

2. Second session (approximately two hours): Trained participants.

   a. The participants were randomly assigned to seating positions to be retained for all remaining sessions.

   b. The experimenter read from a standard script (Appendix B) providing instruction on performing the basic TRAP (without uncertain events). The instructions were tailored to the presentation format assigned to the team. At the appropriate point in the instruction, the participants reviewed a table of TRAP point values (attached to Appendix B) and then took a test on their understanding of the point values (Appendix G). Individual feedback and testing was repeated as required until all participants completed the test perfectly. A slow speed TRAP demonstration trial with commentary was included in the instruction period following point value testing.

   c. The participants performed two practice trials (one at moderate and one at high time stress levels). Following each trial, each participant responded to three workload questions presented on the CRT. The experimenter answered any questions that came up during the practice trials.

   d. The experimenter read from a standard script (Appendix C) providing instruction on performing the TRAP with uncertain events. The participants read along from copies of the instructions and interacted with a slow speed TRAP demonstration trial including uncertain events.

   e. For teams assigned to the heuristics treatment groups, the experimenter read from a standard script (Appendix D) providing instruction on performing the TRAP using the heuristics. The instructions were tailored to the presentation format assigned to the team. The participants read along from copies of the instructions. The participants then received a summary of the heuristics (attached to Appendix D) to retain during the remainder of the session and were encouraged to discuss the heuristics and their decision strategy as a team.

f. For teams assigned to the heuristics treatment groups, the participants took a test on their understanding of the heuristics (Appendix H). Individual feedback and testing was repeated as required until all participants completed the test perfectly.

g. The participants performed four practice trials (two at moderate and two at high time stress levels; the sequence of moderate and high time stress trials was moderate-high-moderate-high). Following each trial, each participant responded to three workload questions presented on the CRT.

3. Third and fourth sessions (approximately two hours each): experimental sessions.

a. The participants were allowed to review a table of TRAP point values and then took a test on their understanding of the point values. Individual feedback and testing were repeated as required until all participants completed the test perfectly.

b. For teams assigned to the heuristics treatment groups, the participants were allowed to review and retain a summary of the heuristics and took a test on their understanding of the heuristics. Individual feedback and testing was repeated as required until all participants completed the test perfectly.

c. The participants performed two test sessions consisting of eight trials each (four at moderate and four at high time stress levels; the sequence of moderate and high time stress trials was randomized in blocks of four trials). Following each trial, each participant responded to three workload questions presented on the CRT. A break was allowed between the two test sessions.

4.3 Summary of Research Environment and Method

This study involved a laboratory experiment using a dynamic group choice task (TRAP) as the experimental task. Subsequent to screening and training, each team of three decision makers completed a total of 32 trials, arranged in 4 test sessions of 8 trials each. Half of the trials were presented at a fast rate of speed and half at a more moderate speed. Each TRAP trial presented a sequence of 64 certain and uncertain events. The teams had insufficient resources to respond to every event, so they had to choose among the available events. Coding schemes for presenting the events varied between teams as did the presence or absence of decision 'euristics provided by the researcher.

The research method outlined in this chapter provided the mechanism by which to capture information on the effects of information presentation form and decision heuristics on group decision making in a dynamic, uncertain environment. The next chapter analyzes the results of the experiment.

5.0 ANALYSIS OF RESULTS

This chapter presents the statistical analysis of the results of the experiment. (Cell means and variances and the raw data are included in Appendix I.) The first section reviews the major results of a related study. The second section defines the primary model used to evaluate the results of this study, and the third section presents the findings using the model. The model used to analyze findings about information seeking behavior and the findings based on the model are presented in the fourth and fifth sections. Similarly, the model and findings concerning resource commitments to uncertain events appear in the sixth and seventh sections. A major section then relates the findings to the experimental hypotheses presented in Chapter 3. The chapter concludes with a summary of the major results of this study.

5.1 Related Results

In a related study run concurrently with this experiment, Kimble, McNeese, and Goodyear examined the effects of emergent leadership on TRAP performance. They determined that a number of variables (age, college year completed, sex composition of team, video game experience, and leadership measured in terms of relative frequency and duration of talking) had no effect on TRAP performance. One variable, experience with using computers, was correlated with performance ($r = .54$, $p < .002$) [KIMB87]. Random assignment of participants to teams, however, resulted in an even distribution of experienced computer users among the treatment groups studied in this experiment, so the results reported here are not confounded with the computer use variable.

5.2 Primary Experimental Model

The results of the experiment were examined using the SAS ANOVA procedure. Except for the analyses of information seeking and resource commitment behaviors related to uncertain events (models to be presented in later sections), the model used for the statistical analysis was

$$
\begin{aligned}
Y_{ijklmn} = {} & u. + \text{time}_i + \text{sess}_j + \text{form}_k + \text{heur}_l + \text{team}_{m(kl)} + \\
& (\text{time*sess})_{ij} + (\text{time*form})_{ik} + (\text{time*heur})_{il} + (\text{time*team})_{im(kl)} + \\
& (\text{sess*form})_{jk} + (\text{sess*heur})_{jl} + (\text{sess*team})_{jm(kl)} + (\text{form*heur})_{kl} + \\
& (\text{time*sess*form})_{ijk} + (\text{time*sess*heur})_{ijl} + (\text{time*form*heur})_{ikl} + \\
& (\text{sess*form*heur})_{jkl} + (\text{time*sess*form*heur})_{ijkl} + e_{n(ijklm)}
\end{aligned}
$$

where

'Y' represents a dependent variable measure (overall TRAP score, proportions of events completed, SWAT ratings, etc.)

'time' is the time stress variable (high or moderate time stress)

'sess' is the practice variable (session 1, 2, 3, or 4)

'form' is the information presentation form variable (color, alphabetic, or conjunctive coding scheme)

'heur' is the suggested decision strategy variable (with or without heuristics)

'team' is a variable that takes into account any differences among the three teams assigned to each combination of treatments (any given team was assigned to only one combination of a form treatment and a heuristics treatment). Since team differences are accounted for in the model, the results related to other variables can be generalized for other teams with more confidence than if team differences were not included.

Table 5.1 provides the degrees of freedom and expected mean squares for the model. A three-way interaction term, (time*sess*team)$_{ijm(kl)}$, was pooled into the error term since no degrees of freedom remained for the error term. As a result, no tests of team effects or of the effects of interactions between the team variable and other variables were provided by the model, but team effects were not a focus of this study.

Tests of the assumptions on which the ANOVA model is based demonstrated that the model is applicable to the results of this study. Specifically, within commonly accepted limits, all observations have the same variance and the error terms are normally distributed.

5.3 Statistical Analysis Using Primary Experimental Model

The primary experimental model was used to analyze findings for seven outcome variables. Each of the following subsections presents the analysis for one of the variables.

5.3.1 Overall Performance

The variable used to measure overall performance was a team score stated as a percentage of the computer model's score for the same trial. Table 5.2 is the ANOVA table for the overall performance variable.

TABLE 5.1 Primary ANOVA Model

Source	DF	Expected Mean Square
time	1	$96\Sigma a_i^2 + 4\sigma_{ae}^2 + \sigma^2$
sess	3	$48\Sigma b_j^2/3 + 2\sigma_{be}^2 + \sigma^2$
form	2	$64\Sigma c_k^2/2 + 8\sigma_e^2 + \sigma^2$
heur	1	$96\Sigma d_l^2 + 8\sigma_e^2 + \sigma^2$
team(form*heur)	18	$8\sigma_e^2 + \sigma^2$
sess*time	3	$24\Sigma\Sigma(ab)_{ij}^2/3 + \sigma_{abe}^2 + \sigma^2$
form*time	2	$32\Sigma\Sigma(ac)_{ik}^2/2 + 4\sigma_{ae}^2 + \sigma^2$
heur*time	1	$48\Sigma\Sigma(ad)_{il}^2 + 4\sigma_{ae}^2 + \sigma^2$
time*team(form*heur)	18	$4\sigma_{ae}^2 + \sigma^2$
form*sess	6	$16\Sigma\Sigma(bc)_{jk}^2/6 + 2\sigma_{be}^2 + \sigma^2$
heur*sess	3	$24\Sigma\Sigma(bd)_{jl}^2/3 + 2\sigma_{be}^2 + \sigma^2$
sess*team(form*heur)	54	$2\sigma_{be}^2 + \sigma^2$
form*heur	2	$32\Sigma\Sigma(cd)_{kl}^2/2 + 8\sigma_e^2 + \sigma^2$
time*sess*form	6	$8\Sigma\Sigma\Sigma(abc)_{ijk}^2/6 + \sigma_{abe}^2 + \sigma^2$
time*sess*heur	3	$12\Sigma\Sigma\Sigma(abd)_{ijl}^2/3 + \sigma_{abe}^2 + \sigma^2$
time*sess*team(form*heur)	54	$\sigma_{abe}^2 + \sigma^2$
time*form*heur	2	$16\Sigma\Sigma\Sigma(acd)_{ikl}^2/2 + 4\sigma_{ae}^2 + \sigma^2$
sess*form*heur	6	$8\Sigma\Sigma\Sigma(bcd)_{jkl}^2/6 + 2\sigma_{be}^2 + \sigma^2$
time*sess*form*heur	6	$4\Sigma\Sigma\Sigma\Sigma(abcd)_{ijkl}^2/6 + \sigma_{abe}^2 + \sigma^2$
error	0	σ^2

There were no statistically significant three-way or higher order interaction effects. There were also no statistically significant two-way interaction effects for sess*time or form*heur. Using the mean square for time*team(form*heur) as an error term, there was no statistically significant effect for form*time ($p = .8013$), but there was an effect for heur*time ($p = .0300$). Using the mean square for sess*team(form*heur) as an error term, there were no statistically significant effects for form*sess ($p = .9112$) or for heur*sess ($p = .9185$). Since the only significant interaction effect (heur*time) was ordinal (see section 5.15.1 below), all the main effects were analyzed. Using the mean square for team(form*heur) as an error term, there was no statistically significant effect for form ($p = .6335$), but there was an effect for heur (p = .0092). Using the mean square for time*team(form*heur) as an error term, there was an effect for time (p = .0001), and, using the mean square for sess*team(form*heur) as an error term, there was an effect for sess (p = .0003).

TABLE 5.2 ANOVA Results, Overall Performance

Source	DF	Sum of Squares	Mean Square
Model	137	13392.97364258	97.75893170
Error	54	990.10228736	18.33522754
Corrected Total	191	14383.07592994	

Source	DF	Sum of Squares	F Value	Pr > F
time	1	7278.855125	382.53	0.0001
sess	3	612.925865	7.31	0.0003
form	2	100.921266	0.47	0.6335
heur	1	917.202435	8.51	0.0092
team(form*heur)	18	1939.782624	(no test)	
sess*time	3	15.466077	0.28	0.8388
form*time	2	8.535733	0.22	0.8013
heur*time	1	105.640107	5.55	0.0300
time*team(form*heur)	18	342.507240	(no test)	
form*sess	6	57.445468	0.34	0.9112
heur*sess	3	13.964643	0.17	0.9185
sess*team(form*heur)	54	1509.826241	(no test)	
form*heur	2	148.144004	0.69	0.5156
time*sess*form	6	23.595976	0.43	0.7331
time*sess*heur	3	63.555863	0.76	0.6048
time*form*heur	2	71.566409	1.88	0.1813
sess*form*heur	6	23.855415	0.14	0.9898
time*sess*form*heur	6	139.182151	1.27	0.2889

The overall performance score was expressed as a team's percentage of the computer model's score to account for potential differences in difficulty among the trials. Raw team scores were also analyzed to provide an indication as to the need for standardizing team scores by the model scores. Table 5.3 presents the ANOVA results for raw team scores.

There were no statistically significant three-way or higher order interaction effects. There were also no statistically significant two-way interaction effects for sess*time or form*heur. Using the mean square for time*team(form*heur) as an error term, there was no statistically significant effect for form*time (p = .6526), but there was an effect for heur*time (p = .0139). Using the mean square for sess*team(form*heur) as an error term, there were no statistically significant effects for form*sess (p = .6076) or for heur*sess (p = .9299). Since the only significant interaction effect (heur*time) was ordinal (see section 5.15.1 below), all the main effects were analyzed. Using the mean square for team(form*heur) as an error term, there was no statistically significant effect for form (p = .4919), but there was an effect for heur (p = .0123). Using the mean square for time*team(form*heur) as an error term, there was an effect for time (p = .0001), and, using the mean square for sess*team(form*heur) as an error term, there was an effect for sess (p = .0001).

TABLE 5.3 ANOVA Table, Team Score

Source	DF	Sum of Squares	Mean Square
Model	137	57161.23725260	417.2353084
Error	54	3962.00742188	73.3705078
Corrected Total	191	61123.24467448	

Source	DF	Sum of Squares	F Value	Pr > F
time	1	32148.394805	419.98	0.0001
sess	3	2612.553893	9.94	0.0001
form	2	705.032214	0.74	0.4919
heur	1	3699.979805	7.75	0.0123
team(form*heur)	18	8596.036641	(no test)	
sess*time	3	248.032747	1.13	0.3464
form*time	2	66.908203	0.44	0.6526
heur*time	1	568.735430	7.43	0.0139
time*team(form*heur)	18	1377.848516	(no test)	
form*sess	6	397.135599	0.76	0.6076
heur*sess	3	39.154831	0.15	0.9299
sess*team(form*heur)	54	4726.673047	(no test)	
form*heur	2	417.487578	0.44	0.6526
time*sess*form	6	186.280456	0.85	0.4746
time*sess*heur	3	328.421276	1.43	0.2212
time*form*heur	2	137.713359	0.90	0.4243
sess*form*heur	6	71.502317	0.14	0.9910
time*sess*form*heur	6	531.346536	1.21	0.3170

Since the same effects were significant at comparable levels of significance for the score expressed either as a percentage of the computer model score or as a raw team score, it was assumed that the distribution of difficult trials was random enough to wash out any effects of differences in trial difficulty. The remaining variables, therefore, were analyzed as simple team measures rather than as percentages of model performance.

5.3.2 Proportion from Certain-Valued Events

Behavioral variables used to help explain performance differences included the proportion of a team's points earned from certain-valued events. Table 5.4 presents the ANOVA results for the proportion of the score from certain-valued events.

TABLE 5.4 ANOVA Results, Proportion Certain

Source	DF	Sum of Squares	Mean Square
Model	137	6.23149651	0.04548539
Error	54	0.16392872	0.00303572
Corrected Total	191	6.39542723	

Source	DF	Sum of Squares	F Value	Pr > F
time	1	0.01584329	1.68	0.2113
sess	3	0.09445643	4.33	0.0083
form	2	0.04521623	0.12	0.8898
heur	1	1.08747001	5.66	0.0287
team(form*heur)	18	3.46134581	(no test)	
sess*time	3	0.01525253	1.67	0.1833
form*time	2	0.00824559	0.44	0.6526
heur*time	1	0.03366696	3.57	0.0751
time*team(form*heur)	18	0.16978226	(no test)	
form*sess	6	0.05701637	1.31	0.2705
heur*sess	3	0.04844589	2.22	0.0964
sess*team(form*heur)	54	0.39300405	(no test)	
form*heur	2	0.66362109	1.73	0.2063
time*sess*form	6	0.00147495	0.16	0.9215
time*sess*heur	3	0.02362310	1.30	0.2744
time*form*heur	2	0.00168668	0.09	0.9149
sess*form*heur	6	0.08795494	2.01	0.0796
time*sess*form*heur	6	0.02339233	1.28	0.2801

There were no statistically significant three-way or higher order interaction effects. There were also no statistically significant two-way interaction effects for sess*time or form*heur. Using the mean square for time*team(form*heur) as an error term, there was no statistically significant effect for form*time (p = .6526) or for heur*time (p = .0751). Using the mean square for sess*team(form*heur) as an error term, there were no statistically significant effects for form*sess (p = .2705) or for heur*sess (p = .0964). Since there were no significant interaction effects, all the main effects were analyzed. Using the mean square for team(form*heur) as an error term, there was no statistically significant effect for form (p = .8898), but there was an effect for heur (p = .0287). Using the mean square for time*team(form*heur) as an error term, there was no effect for time (p = .2113), but, using the mean square for sess*team(form*heur) as an error term, there was an effect for sess (p = .0083).

5.3.3 1-Player-1-Point-per-Player Events

Behavioral variables also included the proportion of particular types of certain-valued events to which teams committed resources. Table 5.5 presents the ANOVA results for the 1-point events.

TABLE 5.5 ANOVA Results, 1-Point Events

Source	DF	Sum of Squares	Mean Square
Model	137	0.73000886	0.00532853
Error	54	0.13144062	0.00243409
Corrected Total	191	0.86144948	

Source	DF	Sum of Squares	F Value	Pr > F
time	1	0.01219219	4.90	0.0400
sess	3	0.00813490	0.89	0.4527
form	2	0.01065104	0.38	0.6862
heur	1	0.08542969	6.17	0.0231
team(form*heur)	18	0.24922188	(no test)	
sess*time	3	0.00577656	0.79	0.5042
form*time	2	0.00394687	0.79	0.4675
heur*time	1	0.00001302	0.01	0.9431
time*team(form*heur)	18	0.04477187	(no test)	
form*sess	6	0.01733229	0.95	0.4695
heur*sess	3	0.00498906	0.55	0.6534
sess*team(form*heur)	54	0.16469063	(no test)	
form*heur	2	0.07583437	2.74	0.0915
time*sess*form	6	0.01312812	0.90	0.5026
time*sess*heur	3	0.00428906	0.59	0.6259
time*form*heur	2	0.00526354	1.06	0.3677
sess*form*heur	6	0.01521562	0.83	0.5509
time*sess*form*heur	6	0.00912813	0.63	0.7094

There were no statistically significant three-way or higher order interaction effects. There were also no two-way interaction effects for sess*time or form*heur. Using the mean square for time*team(form*heur) as an error term, there was no statistically significant effect for form*time (p = .4675) or for heur*time (p = .9431). Using the mean square for sess*team(form*heur) as an error term, there were no effects for form*sess (p = .4695) or for heur*sess (p = .6534). Since there were no significant interaction effects, all the main effects were analyzed. Using the mean square for team(form*heur) as an error term, there was no statistically significant effect for form (p = .6862), but there was an effect for heur (p = .0231). Using the mean square for time*team(form*heur) as an error term, there was an effect for time (p = .0400), but, using the mean square for sess*team(form*heur) as an error term, there was no effect for sess (p = .4527).

5.3.4 2-Player-2-Points-per-Player Events

Table 5.6 presents the ANOVA results for the 4-point events.

TABLE 5.6 ANOVA Results, 4-Point Events

Source	DF	Sum of Squares	Mean Square
Model	137	0.43331042	0.00316285
Error	54	0.05735625	0.00106215
Corrected Total	191	0.49066667	

Source	DF	Sum of Squares	F Value	Pr > F
time	1	0.00880208	5.76	0.0274
sess	3	0.00164583	0.32	0.8116
form	2	0.02026354	1.23	0.3164
heur	1	0.05535208	6.71	0.0185
team(form*heur)	18	0.14856875	(no test)	
sess*time	3	0.00429375	1.35	0.2687
form*time	2	0.00400729	1.31	0.2939
heur*time	1	0.00003333	0.02	0.8842
time*team(form*heur)	18	0.02749375	(no test)	
form*sess	6	0.00770729	0.75	0.6148
heur*sess	3	0.00726042	1.41	0.2507
sess*team(form*heur)	54	0.09288125	(no test)	
form*heur	2	0.01283229	0.78	0.4744
time*sess*form	6	0.009[illegible]2188	1.49	0.1978
time*sess*heur	3	0.016[illegible]387	5.08	0.0036
time*form*heur	2	0.00706354	2.31	0.1277
sess*form*heur	6	0.00515521	0.50	0.8059
time*sess*form*heur	6	0.00423229	0.66	0.6780

There was one statistically significant three-way interaction (time*sess*heur). There were no statistically significant two-way interaction effects for sess*time or form*heur. Using the mean square for time*team(form*heur) as an error term, there was no statistically significant effect for form*time ($p = .2939$). Using the mean square for sess*team(form*heur) as an error term, there was no statistically significant effects for form*sess ($p = .6145$). Since form was the only variable not involved in significant interaction effects, only the main effects for form were analyzed. Using the mean square for team(form*heur) as an error term, there was no statistically significant effect for form ($p = .3164$).

5.3.5 <u>2-Player-4-Points-per-Player Events</u>

Table 5.7 presents the ANOVA results for the proportion of 8-point events completed.

TABLE 5.7 ANOVA Results, 8-Point Events

Source	DF	Sum of Squares	Mean Square
Model	137	7.85714167	0.05735140
Error	54	0.40000625	0.00740752
Corrected Total	191	8.25714792	

Source	DF	Sum of Squares	F Value	Pr > F
time	1	0.25960208	12.90	0.0021
sess	3	0.12633958	3.18	0.0310
form	2	0.01243854	0.03	0.9752
heur	1	0.14520000	0.59	0.4534
team(form*heur)	18	4.45080875	(no test)	
sess*time	3	0.04543958	2.04	0.1185
form*time	2	0.00553854	0.14	0.8724
heur*time	1	0.07083333	3.50	0.0776
time*team(form*heur)	18	0.36236875	(no test)	
form*sess	6	0.04756979	0.60	0.7296
heur*sess	3	0.08741667	2.20	0.0983
sess*team(form*heur)	54	0.71445625	(no test)	
form*heur	2	1.31186563	2.65	0.0978
time*sess*form	6	0.03201979	0.72	0.6349
time*sess*heur	3	0.00960000	0.43	0.7309
time*form*heur	2	0.00513229	0.13	0.8811
sess*form*heur	6	0.13079271	1.65	0.1520
time*sess*form*heur	6	0.03995937	0.90	0.5024

There were no statistically significant three-way or higher order interaction effects. There were also no significant two-way interaction effects for sess*time or form*heur. Using the mean square for time*team(form*heur) as an error term, there was no significant effect for form*time (p = .8724) or for heur*time (p = .0776). Using the mean square for sess*team(form*heur) as an error term, there were no significant effects for form*sess (p = .7296) or for heur*sess (p = .0983). Since there were no significant interaction effects, all the main effects were analyzed. Using the mean square for team(form*heur) as an error term, there was no statistically significant effect for form (p = .8898) or for heur (p = .4534). Using the mean square for time*team(form*heur) as an error term, there was an effect for time (p = .0021), and, using the mean square for sess*team(form*heur) as an error term, there was an effect for sess (p = .0310).

5.3.6 <u>3-Player-5-Points-per-Player Events</u>

Table 5.8 presents the ANOVA results for 15-point events.

TABLE 5.8 ANOVA Results, 15-Point Events

Source	DF	Sum of Squares	Mean Square
Model	137	2.79905417	0.02043105
Error	54	0.65873750	0.01219884
Corrected Total	191	3.45779167	

Source	DF	Sum of Squares	F Value	Pr > F
time	1	0.00200208	0.14	0.7144
sess	3	0.03395417	0.62	0.6023
form	2	0.01073229	0.10	0.9081
heur	1	0.04200833	0.76	0.3951
team(form*heur)	18	0.99608750	(no test)	
sess*time	3	0.01051042	0.29	0.8344
form*time	2	0.09031354	3.12	0.0687
heur*time	1	0.00005208	0.00	0.9528
time*team(form*heur)	18	0.26066250	(no test)	
form*sess	6	0.07395521	0.68	0.6664
heur*sess	3	0.02934583	0.54	0.6572
sess*team(form*heur)	54	0.97881250	(no test)	
form*heur	2	0.10501354	0.95	0.4057
time*sess*form	6	0.03342396	0.46	0.8371
time*sess*heur	3	0.04311875	1.18	0.3266
time*form*heur	2	0.03226979	1.11	0.3498
sess*form*heur	6	0.04848229	0.45	0.8448
time*sess*form*heur	6	0.00830938	0.11	0.9945

There were no significant three- or four-way interaction effects. There were also no significant interaction effects for sess*time or form*heur. Using the mean square for time*team(form*heur) as an error term, there was no significant effect for form*time (p = .0687) or for heur*time (p = .9528). Using the mean square for sess*team(form*heur) as an error term, there were no significant effects for form*sess (p = .6664) or for heur*sess (p = .6572). Since there were no significant interaction effects, all the main effects were analyzed. Using the mean square for team(form*heur) as an error term, there was no significant effect for form (p = .9081) or for heur (p = .3951). Using the mean square for time*team(form*heur), there was no effect for time (p = .7144), and, using the mean square for sess*team(form*heur), there was no effect for sess (p = .6023).

5.3.7 Perceived Workload

Table 5.9 presents the ANOVA results for workload perceptions, measured using the Subjective Workload Assessment Technique (SWAT).

TABLE 5.9 ANOVA Results, SWAT

Source	DF	Sum of Squares	Mean Square
Model	137	41114.24336661	300.10396618
Error	54	1722.47847222	31.89774949
Corrected Total	191	42836.72183883	

Source	DF	Sum of Squares	F Value	Pr > F
time	1	11817.39421875	98.71	0.0001
sess	3	1978.07366175	8.98	0.0001
form	2	2012.95108579	1.06	0.3682
heur	1	79.07472367	0.08	0.7765
team(form*heur)	18	17145.11010417	(no test)	
sess*time	3	154.69548032	1.62	0.1962
form*time	2	315.51362196	1.32	0.2924
heur*time	1	71.70370370	0.60	0.4490
time*team(form*heur)	18	2155.03434028	(no test)	
form*sess	6	198.47395761	0.45	0.8415
heur*sess	3	225.66792101	1.02	0.3892
sess*team(form*heur)	54	3966.06142361	(no test)	
form*heur	2	236.41929326	0.12	0.8840
time*sess*form	6	58.36088903	0.30	0.9317
time*sess*heur	3	13.65769676	0.14	0.9339
time*form*heur	2	72.46984447	0.30	0.7425
sess*form*heur	6	548.26452908	1.24	0.2988
time*sess*form*heur	6	65.31687138	0.34	0.9119

There were no statistically significant three-way or higher order interaction effects. There were also no significant two-way interaction effects for sess*time or form*heur. Using the mean square for time*team(form*heur) as an error term, there was no statistically significant effect for form*time ($p = .2924$) or for heur*time ($p = .4490$). Using the mean square for sess*team(form*heur) as an error term, there were no significant effects for form*sess ($p = .8415$) or for heur*sess ($p = .3892$). Since there were no significant interaction effects, all the main effects were analyzed. Using the mean square for team(form*heur) as an error term, there was no significant effect for form ($p = .3682$) or for heur ($p = .7765$). Using the mean square for time*team(form*heur) as an error term, there was an effect for time ($p = .0001$), and, using the mean square for sess*team(form*heur) as an error term, there was an effect for sess ($p = .0001$).

5.4 ANOVA Model for Information Seeking

The model used for the statistical analysis of the proportion of uncertain events about which teams sought additional information was

$$Y_{ijklmn} = u. + time_i + sess_j + type_k + heur_l + team_{m(l)} + (time*sess)_{ij} + (time*type)_{ik} + (time*heur)_{il} + (time*team)_{im(l)} + (sess*type)_{jk} + (sess*heur)_{jl} + (sess*team)_{jm(l)} + (type*heur)_{kl} + (type*team)_{km(l)} + (time*sess*type)_{ijk} + (time*sess*heur)_{ijl} + (time*sess*team)_{ijm(l)} + (time*type*heur)_{ikl} + (time*type*team)_{ikm(l)} + (sess*type*heur)_{jkl} + (sess*type*team)_{jkm(l)} + (time*sess*type*heur)_{ijkl} + e_{n(ijklm)}$$

where

'Y' represents the proportion of uncertain events about which additional information is sought

'time' is the time stress variable (high or moderate time stress)

'sess' is the practice variable (session 1, 2, 3, or 4)

'type' is the specific type of uncertain event involved (H21, H9, L84, or L36)

'heur' is the suggested decision strategy variable (with or without heuristics)

'team' is a variable that takes into account any differences among the 12 teams assigned to each heuristics treatment.

The information presentation form variable was not included in the model because the symbols for uncertain events (black rectangles) were identical for all treatment groups. (To confirm that the information presentation form variable was not required in the model, a model including the form variable was analyzed. There were no statistically significant interaction effects involving information presentation form, nor was there a main effect for form ($p = .9458$).)

TABLE 5.10 ANOVA Model for Information Seeking

Source	DF	Expected Mean Square
time	1	$384\Sigma a_i^2 + 16\sigma_{ae}^2 + \sigma^2$
sess	3	$192\Sigma b_j^2/3 + 8\sigma_{be}^2 + \sigma^2$
type	3	$192\Sigma c_k^2/3 + 8\sigma_e^2 + \sigma^2$
heur	1	$384\Sigma d_l^2 + 32\sigma_e^2 + \sigma^2$
team(heur)	22	$32\sigma_e^2 + \sigma^2$
sess*time	3	$96\Sigma\Sigma(ab)_{ij}^2/3 + 4\sigma_{abe}^2 + \sigma^2$
type*time	3	$96\Sigma\Sigma(ac)_{ik}^2/3 + 4\sigma_{ace}^2 + \sigma^2$
heur*time	1	$192\Sigma\Sigma(ad)_{il}^2 + 16\sigma_{ae}^2 + \sigma^2$
time*team(heur)	22	$16\sigma_{ae}^2 + \sigma^2$
type*sess	9	$48\Sigma\Sigma(bc)_{jk}^2/9 + 2\sigma_{bce}^2 + \sigma^2$
heur*sess	3	$96\Sigma\Sigma(bd)_{jl}^2/3 + 8\sigma_{be}^2 + \sigma^2$
sess*team(heur)	66	$8\sigma_{be}^2 + \sigma^2$
type*heur	3	$96\Sigma\Sigma(cd)_{kl}^2/3 + 8\sigma_{ce}^2 + \sigma^2$
type*team(heur)	66	$8\sigma_{ce}^2 + \sigma^2$
time*sess*type	9	$24\Sigma\Sigma\Sigma(abc)_{ijk}^2/9 + \sigma_{abce}^2 + \sigma^2$
time*sess*heur	3	$48\Sigma\Sigma\Sigma(abd)_{ijl}^2/3 + 4\sigma_{abe}^2 + \sigma^2$
time*sess*team(heur)	66	$4\sigma_{abe}^2 + \sigma^2$
time*type*heur	3	$48\Sigma\Sigma\Sigma(acd)_{ikl}^2/3 + 4\sigma_{ace}^2 + \sigma^2$
time*type*team(heur)	66	$4\sigma_{ace}^2 + \sigma^2$
sess*type*heur	9	$24\Sigma\Sigma\Sigma(bcd)_{jkl}^2/9 + 2\sigma_{bce}^2 + \sigma^2$
sess*type*team(heur)	198	$2\sigma_{bce}^2 + \sigma^2$
time*sess*type*heur	9	$12\Sigma\Sigma\Sigma\Sigma(abcd)_{ijkl}^2/9 + \sigma_{abce}^2 + \sigma^2$
time*sess*type*team(heur)	198	$\sigma_{abce}^2 + \sigma^2$
error	0	σ^2

Table 5.10 shows the model's degrees of freedom and expected mean squares. A four-way interaction term, $(time*sess*type*team)_{ijkm(l)}$, was pooled into the error term since no degrees of freedom remained for the error term. As a result, no tests of team effects or of the effects of interactions between the team variable and other variables were provided by the model, but team effects were not a focus of this study.

Tests of the assumptions on which the ANOVA model is based demonstrated that the model is applicable to the results of this study. Specifically, within commonly accepted limits, all observations have the same variance and the error terms are normally distributed.

5.5 Statistical Analysis Using ANOVA Model for Information Seeking

Table 5.11 is the ANOVA table for the proportion of the uncertain events about which a team sought additional information.

TABLE 5.11 ANOVA Results, Information Seeking

Source	DF	Sum of Squares	Mean Square
Model	569	31.93649740	0.05612741
Error	198	2.14911458	0.01085411
Corrected Total	767	34.08561198	

Source	DF	Sum of Squares	F Value	Pr > F
time	1	1.45255208	73.82	0.0001
sess	3	0.27910156	4.00	0.0112
type	3	0.08944010	2.55	0.0631
heur	1	7.14949219	9.81	0.0048
team(heur)	22	16.03361979	(no test)	
sess*time	3	0.03177083	1.43	0.2425
type*time	3	0.03002604	0.92	0.4343
heur*time	1	0.02520833	1.28	0.2699
time*team(heur)	22	0.43286458	(no test)	
type*sess	9	0.11373698	1.05	0.4010
heur*sess	3	0.10035156	1.44	0.2400
sess*team(heur)	66	1.53679687	(no test)	
type*heur	3	0.01720052	0.49	0.6901
type*team(heur)	66	0.77148438	(no test)	
time*sess*type	9	0.11419271	1.17	0.3168
time*sess*heur	3	0.00567708	0.26	0.8574
time*sess*team(heur)	66	0.48942708	(no test)	
time*type*heur	3	0.00742188	0.23	0.8763
time*type*team(heur)	66	0.71505208	(no test)	
sess*type*heur	9	0.09858073	0.91	0.5167
sess*type*team(heur)	198	2.38080729	(no test)	
time*sess*type*heur	9	0.06169271	0.63	0.7693

There were no statistically significant three-way or higher order interaction effects. There were also no significant two-way interaction effects for sess*time, type*time, sess*type, or type*heur. Using the mean square for time*team(heur) as an error term, there was no significant effect for heur*time (p = .2699). Using the mean square for sess*team(heur) as an error term, there was no significant effect for heur*sess (p = .2400). Since there were no significant interaction effects, all the main effects were analyzed. Using the mean square for team(heur) as an error term, there was an effect for heur (p = .0048). Using the mean square for time*team(heur) as an error term, there was also an effect for time (p = .0001), and, using the mean square for sess*team(heur) as an error term, there was an effect for sess (p = .0112). Using the mean square for type*team(heur) as an error term, there was no statistically significant effect for type (p = .0631).

5.6 ANOVA Model for Resource Commitments to Uncertain Events

The model used for the statistical analysis of the proportion of uncertain events to which teams committed resources subsequent to seeking additional information was

$$Y_{ijklm} = u_{.} + time_{i} + type_{j} + heur_{k} + team_{l(k)} + (time*type)_{ij} + (time*heur)_{ik} + (time*team)_{il(k)} + (type*heur)_{jk} + (type*team)_{jl(k)} + (time*type*heur)_{ijk} + e_{m(ijkl)}$$

where

'Y' represents the proportion of uncertain events to which resources are committed subsequent to seeking additional information. It is measured in terms of a ratio of the number of uncertain events completed to the number of uncertain events about which additional information was sought (not as a ratio of uncertain events completed to total uncertain events presented).

'time' is the time stress variable (high or moderate time stress)

'type' represents the specific type of uncertain event involved (H21, H9, L84, or L36)

'heur' is the suggested decision strategy variable (with or without heuristics)

'team' is a variable that takes into account any differences among the 12 teams assigned to each heuristics treatment.

The experimental model used to analyze resource commitments to uncertain events does not include the practice variable. A very few teams chose to seek additional information about so few uncertain events that, for a given experimental session, it was possible that a team had no uncertain events of some particular type available to complete. Since proportions with denominators of zero could not be analyzed, some alternate analysis mechanism was required. Data involving denominators of zero could be ignored, creating unequal cell sizes. The SAS General Linear Models procedure provides for analysis involving unequal cell sizes, but computer memory limitations precluded analysis with a complete model. An analysis of a limited model (only main effects and two-way interactions involving the time pressure, practice, event type, heuristics, and team variables) revealed that there was no main effect for the practice variable nor were there any two-way interaction effects involving the practice variable. Therefore, the practice variable was dropped from the model, and data for each team was averaged across the four sessions. Further, since every team sought additional information about at least one uncertain event of each type sometime during the experiment, no data involving denominators of zero remained. Therefore, a model ignoring the session variable could be analyzed using the SAS ANOVA procedure.

The information presentation form variable was not included in the model because the symbols for uncertain events (black rectangles) were identical for all treatment groups. (To confirm that the information presentation form variable was not required in the model, a model including the form variable was analyzed. There were no statistically significant interaction effects involving information presentation form, nor was there a main effect for form (p = .6338).)

Table 5.12 provides the degrees of freedom and expected mean squares for the model. A three-way interaction term, (time*type*team)$_{ijl(k)}$, was pooled into the error term since no degrees of freedom remained for the error term. As a result, no tests of team effects or of the effects of interactions between the team variable and other variables were provided by the model, but team effects were not a focus of this study.

TABLE 5.12 ANOVA Model for Resource Commitments to Uncertain Events

Source	DF	Expected Mean Square
time	1	$96\Sigma a_i^2 + 4\sigma_{ad}^2 + \sigma^2$
type	3	$48\Sigma b_j^2/3 + 2\sigma_{bd}^2 + \sigma^2$
heur	1	$96\Sigma c_k^2 + 8\sigma_d^2 + \sigma^2$
team(heur)	22	$8\sigma_d^2 + \sigma^2$
type*time	3	$24\Sigma\Sigma(ab)_{ij}^2/3 + \sigma_{abd}^2 + \sigma^2$
heur*time	1	$48\Sigma\Sigma(ac)_{ik}^2 + 4\sigma_{ad}^2 + \sigma^2$
time*team(heur)	22	$4\sigma_{ad}^2 + \sigma^2$
type*heur	3	$24\Sigma\Sigma(bc)_{jk}^2/3 + 2\sigma_{bd}^2 + \sigma^2$
type*team(heur)	66	$2\sigma_{bd}^2 + \sigma^2$
time*type*heur	3	$12\Sigma\Sigma\Sigma(abc)_{ijk}^2/3 + \sigma_{abd}^2 + \sigma^2$
time*type*team(heur)	66	$\sigma_{abd}^2 + \sigma^2$
error	0	σ^2

Tests of the assumptions on which the ANOVA model is based demonstrated that the model is applicable, with reservations, to the results of this study. Specifically, the variance for teams with heuristics was smaller than for teams without heuristics. The error terms were approximately normally distributed. No standard transformation reduced the difference in variability. Since the test was at the commonly accepted limit and no better model existed, the model was accepted as applicable for the results of the study.)

5.7 Statistical Analysis Using ANOVA Model for Resource Commitments to Uncertain Events

The variable used to measure resource commitments to uncertain events was the proportion of uncertain events of a particular type to which resources were committed subsequent to seeking information. Table 5.13 is the ANOVA table for the resource commitment variable.

The three-way interaction (time*type*heur) was not statistically significant. There was also no statistically significant two-way interaction effects for type*time. Using the mean square for time*team(heur) as an error term, there was no statistically significant effect for heur*time ($p = .1385$). Using the mean square for type*team(heur) as an error term, there was an effect for type*heur (p =

.0001). Since only time was not involved in any significant interaction effects, only the main effects for time were analyzed. Using the mean square for time*team(heur) as an error term, there was no statistically significant effect for time (p = .9874).

TABLE 5.13 ANOVA Results, Resource Commitments to Uncertain Events

Source	DF	Sum of Squares	Mean Square
Model	125	34.07965844	0.27263727
Error	66	0.22582388	0.00342157
Corrected Total	191	34.30548231	

Source	DF	Sum of Squares	F Value	Pr > F
time	1	0.00000170	0.00	0.9874
type	3	22.91712950	110.98	0.0001
heur	1	1.10962269	10.65	0.0036
team(heur)	22	2.29129487	(no test)	
type*time	3	0.01171740	1.14	0.3389
heur*time	1	0.01579571	2.36	0.1385
time*team(heur)	22	0.14706877	(no test)	
type*heur	3	3.04281147	14.74	0.0001
type*team(heur)	66	4.54287261	(no test)	
time*type*heur	3	0.00134371	0.13	0.9414

5.8 Findings Related to the Hypotheses

The following subsections relate the findings outlined above to the hypotheses presented in Chapter 3.

5.8.1 Effects of Information Presentation Form

This research compares the impact of three coding schemes: two single-featured schemes (color and alphabetic) and a conjunctive scheme (combination of color and alphabetic). The following two subsections repeat the hypotheses and present findings concerning the effects of information presentation form on decision quality and perceived workload.

5.8.1.1 Information Presentation Form and Decision Quality

H1a. The quality of team decisions in the TRAP will be higher for teams confronted with single-featured (either alphabetic or color-coded) event symbols than for teams confronted with events represented by conjunctions of features. However, there will be no difference in decision quality between teams using an alphabetic coding scheme and teams using a color coding scheme.

The primary measure of decision quality in performing the TRAP was the ratio of a team's score on a trial to the computer model's score on the same trial. The ratio of a team's points earned from certain-valued events to the team's total points provided a behavioral measure to help explain overall performance differences; high quality decision making is indicated by approaching the ratio achieved by the computer model. Data on the proportions of various types of certain-valued events completed was also analyzed; high quality decision making is indicated by low proportions of low-value events completed and high proportions of high-value events completed.

The results of this study suggest that information presentation form does not affect overall decision quality on the TRAP. Using the ratio of team score to model score as a measure, there were no significant differences among the form treatments ($p = .6335$). Teams using the color coding scheme earned 74.4 percent of the points earned by the model on the same trials, teams using the alphabetic scheme 73.0 percent, and teams using the conjunctive scheme 72.7 percent. It should be noted that the tests were powerful enough to detect effects of other variables. The power of the F test to detect differences among information presentation form treatments of 4 percent of the model score (comparable to other detected differences) given the variability experienced in this study exceeded 99 percent.

The ratio of team score to model score is an overall measure of team performance, but the same level of performance could be achieved in a variety of ways. Other measures that describe how a team behaved with respect to specific features of the TRAP help to explain differences in performance. Specifically, two additional measures were used in this study. The relative emphasis that a team placed on certain and uncertain events was captured in the ratio of a team's points earned from certain-valued events to the team's total points. At a finer level of detail, a second behavioral measure examined the proportion of events of each type completed by a team.

Using the ratio of a team's points earned from certain-valued events to the team's total points as a measure, there were still no significant differences among the information presentation form treatments (p = .8898). Teams using the color coding scheme earned 50.1 percent of their points from certain-valued events, teams using the alphabetic scheme 52.0 percent, and teams using the conjunctive scheme 48.2 percent. By comparison, the model earned 45.7 percent of its points from certain-valued events.

Similarly, information presentation form had no effects on the proportions of specific certain-valued events completed. Completion rates for two low-value events (1-player-1-point-per-player and 2-player-2-points-per-player) and two high-value events (3-player-5-points-per-player and 2-player-4-points-per-player) were analyzed. A third type of low-value event, 3-player-1-point-per-player, could not be statistically analyzed since only one such event was completed by any team (a team using the conjunctive coding scheme). There were no significant differences among the form treatments for completion rates of any of the analyzed event types:

1-player-1-point-per-player	p = .6862
2-player-2-points-per-player	p = .3164
3-player-5-points-per-player	p = .9081
2-player-4-points-per-player	p = .9752

Hypothesis H1a, then, was partially supported by the results of this study. The findings supported the expected lack of difference in decision quality between teams using different single-featured coding schemes. However, the results did not support the expected difference in decision quality between teams using single-featured schemes and those using a conjunctive scheme.

5.8.1.2 <u>Information Presentation Form and Perceived Workload</u>

> H1b. The perceived workload in the TRAP will be lower for teams confronted with single-featured (either alphabetic or color-coded) event symbols than for teams confronted with events represented by conjunctions of features. However, there will be no difference in perceived workload between teams using an alphabetic coding scheme and teams using a color coding scheme.

The single measure of perceived workload in performing the TRAP was the average of team member Subjective Workload Assessment Technique (SWAT) ratings. SWAT ratings may range on a scale from 0 to 100 (see Appendix A). The results of this study suggest that information presentation form does not affect perceptions of workload associated with performing the TRAP. There were no significant differences in SWAT ratings among the information presentation form treatments ($p = .3682$).

Hypothesis H1b, then, was partially supported by the results of this study. The findings supported the expected lack of difference in perceived workload between teams using different single-featured coding schemes. However, they did not support the expected difference in perceived workload between teams using single-featured schemes and those using a conjunctive scheme.

5.8.2 <u>Effects of Suggested Decision Strategy</u>

This research assesses the impact of provision and discussion of decision heuristics by comparing performance with the heuristics to performance without the heuristics. The following two subsections repeat the hypotheses and present findings concerning the effects of the suggested decision strategy on decision quality and perceived workload.

5.8.2.1 <u>Suggested Decision Strategy and Decision Quality</u>

Hypotheses and findings concerning the effects of the suggested decision strategy on decision quality are presented in two parts. Effects on overall decision quality will be addressed first followed by an assessment of the particular effects on the quality of decisions made under uncertainty.

5.8.2.1.1 <u>Effects on Overall Decision Quality</u>.

> H2a(1). The quality of team decision in the TRAP will be higher with provision and discussion of decision heuristics than without provision and discussion of decision heuristics.

In this study, overall decision quality was affected by the presence or absence of a suggested decision strategy. Ratios of team scores to model scores were significantly higher with heuristics (75.5 percent of model) than without heuristics (71.2 percent of model) ($p = .0092$).

Using the ratio of a team's points earned from certain-valued events to the team's total points as a behavioral measure, teams with heuristics earned a significantly lower proportion of their points from certain-valued events (42.6 percent) than did teams without heuristics (57.6 percent) ($p = .029$). For comparison, the model earned 45.7

percent of its points from certain-valued events. Teams with heuristics behaved more like the model than did teams without heuristics.

The heuristics treatment also affected the proportions of some specific certain-valued events completed; teams with heuristics completed fewer low-value events (as recommended in the heuristics) than did teams without heuristics. Specifically, teams with heuristics completed 3.5 percent of the 1-player-1-point-per-player events compared to the 7.7 percent completed by teams without heuristics ($p = .0231$).

Hypothesis H2a(1), then, was supported by the results of this study. The findings supported the expected difference in decision quality between teams with and those without the suggested decision strategy.

5.8.2.1.2 <u>Effects on the Quality of Decisions Under Uncertainty</u>.

> H2a(2). Without the provision and discussion of decision heuristics, teams will seek additional information about and commit resources to uncertain events at a rate different from that anticipated according to expected utility theory. With the provision and discussion of decision heuristics, teams will seek additional information about and commit resources to uncertain events according to expected utility theory.

Differences in how teams dealt with uncertainty were examined in terms of the proportion of uncertain events about which teams sought additional information and the proportion of uncertain events to which resources were committed subsequent to seeking additional information.

5.8.2.1.2.1 <u>Seeking Information About Uncertain Events</u>. The results of this study suggest that the presence or absence of heuristics does affect the proportion of uncertain events about which teams seek additional information ($p = .0048$). Teams with heuristics seek information about significantly more uncertain events (57.9 percent) than do teams without heuristics (38.6 percent). For comparison, the computer model, which uses expected value as the basis for its decisions about uncertain events, sought information about 65.7 percent of the uncertain events.

The portion of hypothesis H2a(2) related to seeking information about uncertain events, then, was supported by the results of this study. Teams with the suggested decision strategy sought additional information about uncertain events at a rate more consistent with expected utility theory than did teams without the suggested decision strategy.

5.8.2.1.2.2 Committing Resources to Uncertain Events. The results of this study suggest that the presence or absence of heuristics does affect the proportion of uncertain events to which teams commit resources subsequent to seeking additional information. Specifically, the interaction between the heuristics treatment and the types of uncertain events was significant ($p = .0001$). Four types of uncertain events were defined by the combination of an event's probability of payoff ('H'igh or 'L'ow) and its possible point value (9, 21, 36, or 84). The possible combinations were H9, H21, L36, and L84. Table 5.14 provides the proportions of each type of uncertain event completed by teams with and teams without heuristics. Proportions completed by the computer model are also included for comparison.

TABLE 5.14 Resource Commitments to Uncertain Events

	H21	H9	L84	L36
With Heuristics	93.1%	0.4%	91.6%	0.5%
Without Heuristics	95.0%	46.6%	73.0%	31.8%
Model	100.0%	4.6%	100.0%	4.2%

Figure 5.1 graphically illustrates the interaction when data points are computed as the difference between the proportion of uncertain events completed by teams and those completed by the model. (The zero line on the figure reflects performance by the model.) The figure shows that teams with heuristics committed resources to uncertain events at rates very similar to the model. Teams without heuristics matched the model for events with a high probability of a large payoff (H21) but deviated from the model on other events. Specifically, teams without heuristics overcommitted to events with low expected utility (H9 and L36) and undercommitted to events with high expected utility but a low probability of payoff (L84).

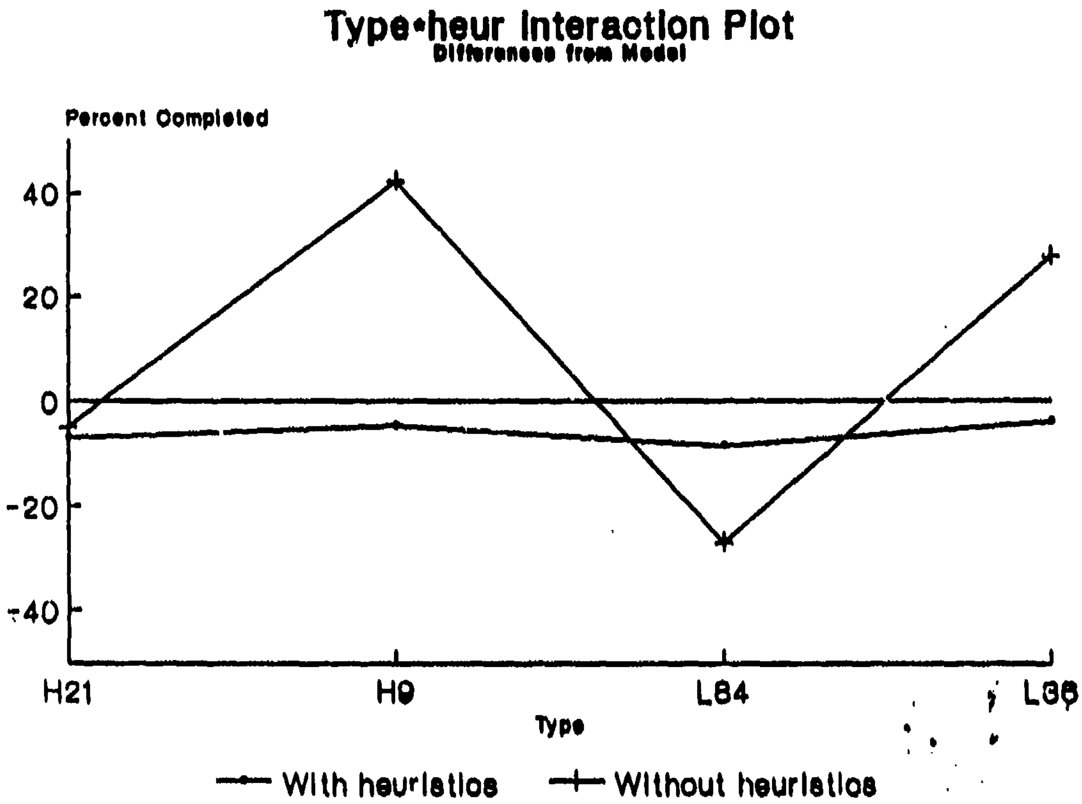

Figure 5.1 Resource Commitments

The portion of hypothesis H2a(2) related to resource commitment to uncertain events, then, was supported by the results of this study. Teams with the suggested decision strategy committed resources to uncertain events at a rate more consistent with expected utility theory than did teams without the suggested decision strategy.

5.8.2.2 Suggested Decision Strategy and Perceived Workload

> H2b. The perceived workload in the TRAP will be lower with provision and discussion of decision heuristics than without provision and discussion of decision heuristics.

In this study, perceived workload, as measured by SWAT ratings, was not affected by the presence or absence of a suggested decision strategy ($p = .7765$). Teams with heuristics rated the TRAP at 39.5 on the 100-point workload scale; teams without heuristics rated the TRAP at 38.2. Hypothesis H2b, then, was not supported by the results of this study.

5.8.3 Effects of Time Stress

This research compares the impact of two levels of time stress. The following two subsections repeat the hypotheses and present findings concerning the effects of time stress on decision quality and perceived workload.

5.8.3.1 Time Stress and Decision Quality.

H3a. The quality of team decisions in the TRAP will be higher under moderate time pressure than under high time pressure.

The results of this study suggest that time stress does affect overall decision quality on the TRAP. Using the ratio of team score to model score as a measure, teams performed significantly better under moderate time pressure (79.5 percent of the model score) than under high time pressure (67.2 percent of the model score) (p = .0001).

Time pressure also had a main effect on the proportions of 1-player-1-point and 2-player-4-points-per-player events completed. In each case, teams completed more events under moderate time pressure than under high time pressure. Table 5.15 shows the proportions of the two types of events completed under high and moderate time pressure, and the significance of the differences. Proportions completed by the model are also shown for comparison. Note that, although teams came closer to behaving like the model under moderate time pressure than under high time pressure, it was not necessarily 'good' to complete more low-valued events.

TABLE 5.15. Events Completed versus Time Pressure

	1 Player 1 Point	2 Players 4 Points each
Model	.073	.589
High Pressure	.048	.362
Moderate Pressure	.064	.436
Significance	p = .040	p = .002

Time stress also affected information seeking activity. Teams sought additional information about significantly more uncertain events under moderate time pressure (52.6 percent) than under high time pressure (43.9 percent) (p = .0001). For comparison, the computer model sought information about 65.7 percent of the uncertain events. Teams behaved more like the model under moderate time pressure than under high time pressure.

Hypothesis H3a, then, was supported by the results of this study. Except for the number of low-valued events completed, the findings supported the expected degradation of decision quality under high time pressure.

5.8.3.2 Time Stress and Perceived Workload

> H3b. The perceived workload in the TRAP will be lower under moderate time pressure than under high time pressure.

Using SWAT ratings as a measure, team perceptions of workload in trials under moderate time pressure were significantly lower (31.0) than in trials under high time pressure (46.7) (p = .0001). Hypothesis H3b, then, was supported by the results of this study.

5.8.4 Effects of Practice

This research assesses the impact of practice on TRAP performance. The following two subsections repeat the hypotheses and present findings concerning the effects of practice on decision quality and perceived workload.

5.8.4.1 Practice and Decision Quality.

> H4a. The quality of team decisions in the TRAP will improve with practice, especially in early sessions.

The results of this study suggest that practice does affect overall decision quality on the TRAP. Using the ratio of team score to model score as a measure, teams performed significantly better in sessions 3 and 4 (75.0 percent of model) than in sessions 1 (70.7 percent of model) and 2 (72.7 percent of model) (p = .0003).

Using the ratio of a team's points earned from certain-valued events to the team's total points as a behavioral measure, teams earned a higher proportion of their points from certain-valued events in session 2 (53.6 percent) than in any other session (session 1, 49.8 percent; session 3, 49.6 percent; session 4, 47.4 percent) (p = .0083). For comparison, the model earned 45.7 percent of its points from certain-valued events; after deviating in session 2, teams returned to a more appropriate proportion during sessions 3 and 4.

In terms of the proportions of specific certain-valued events completed, practice had a main effect only on the proportion of 2-player-4-points-per-player events completed. Teams completed more of these events in session 2 (44.3 percent) than in any other session (38.1 percent in session 1, 39.2 percent in session 3, and 38.0 percent in session 4) ($p = .0310$). For the sake of comparison, the model completed 58.9 percent overall with essentially no variation among sessions).

Practice also affected information seeking activity. Teams sought additional information about significantly more uncertain events in session 4 (51.2 percent) than in either session 1 (47.7 percent) or session 2 (45.9 percent) ($p = .0112$). For comparison, the computer model sought information about 65.7 percent of the uncertain events.

Hypothesis H4a, then, was supported by the results of this study. The findings supported the expected improvement in decision quality over the four experimental sessions. The results for the behavioral variables suggest that the performance improvement was achieved by first improving efficiency in handling certain-valued events and then by more appropriately handling uncertain events.

5.8.4.2 Practice and Perceived Workload

> H4b. The perceived workload in the TRAP will decline with practice, especially in early sessions.

Using SWAT ratings as a measure, team perceptions of workload were significantly lower in session 3 (33.5) than in any other session (session 1, 39.5; session 2, 42.1; session 4, 40.2) ($p = .0001$). Hypothesis H4b, then, is not clearly supported by the results of this study; variations in perceived workload do not match the expected pattern.

5.8.5 Interactive Effects of Time Stress and Information Presentation Form

This research assesses the interaction between time stress and information presentation form. The following two subsections repeat the hypotheses and present findings concerning the impact of the interaction on decision quality and perceived workload.

5.8.5.1 Time Stress/Information Presentation Form and Decision Quality.

> H5a. Time pressure and presentation treatment will interact such that the advantage of single-featured coding over

conjunctive coding for decision quality will be greater under high time pressure than under moderate time pressure. However, the relative effectiveness of alphabetic and color coding for decision quality will remain the same whether under high or moderate time pressure.

The results of this study suggest that there are no interaction effects between time stress and information presentation form on decision quality. Using the ratio of team score to model score as a measure, variations in time pressure did not modify the lack of effects related to the coding schemes ($p = .8013$). There were also no interaction effects between time stress and information presentation form using the ratio of a team's points earned from certain-valued events to the team's total points as a behavioral measure ($p = .8526$).

Hypothesis H5a, then, was partially supported by the results of this study. As expected, time pressure did not modify the relative effectiveness of alphabetic and color coding schemes for decision quality. However, contrary to expectations, time pressure also failed to modify the relative effectiveness of single-featured and conjunctive coding schemes for decision quality.

5.8.5.2 <u>Time Stress/Information Presentation Form and Perceived Workload</u>.

H5b. Time pressure and presentation treatment will interact such that the advantage of single-featured coding over conjunctive coding for perceived workload will be greater under high time pressure than under moderate time pressure. However, the relative impact of alphabetic and color coding on perceived workload will remain the same whether under high or moderate time pressure.

Using SWAT ratings as a measure of perceived workload, there were no interaction effects between time stress and information presentation form ($p = .2924$). Hypothesis H5b, then, was partially supported by the results of this study. As expected, time pressure did not modify the relative impact of alphabetic and color coding. However, contrary to expectations, time pressure also failed to modify the relative impact of single-featured and conjunctive coding on perceived workload.

5.8.6 <u>Interactive Effects of Practice and Information Presentation Form</u>

This research assessed the interaction between practice and information presentation form. The following two subsections repeat the hypotheses and present findings concerning the impact of the interaction on decision quality and perceived workload.

5.8.6.1 <u>Practice/Information Presentation Form and Decision Quality</u>.

> H6a. Practice and presentation treatment will interact such that any differences in the relative effectiveness of alphabetic and color coding for decision quality will attenuate over the four experimental sessions. However, differences in the relative effectiveness of conjunctive and single-featured coding will remain constant over the four experimental sessions.

The results of this study suggest that there are no interaction effects between practice and information presentation form on decision quality. Using the ratio of team score to model score as a measure, practice did not modify the lack of effects related to the coding schemes ($p = .9112$). There were also no interaction effects between practice and information presentation form using the ratio of a team's points earned from certain-valued events to the team's total points as a behavioral measure ($p = .2705$).

Hypothesis H6a, then, was partially supported by the results of this study. As expected, practice did not modify the relative effectiveness of conjunctive and single-featured coding schemes for decision quality. However, contrary to expectations, practice also failed to modify the relative effectivenss of alphabetic and color coding schemes for decision quality.

5.8.6.2 <u>Practice/Information Presentation Form and Perceived Workload</u>.

> H6b. Practice and presentation treatment will interact such that any differences in perceived workload associated with alphabetic and color coding will attenuate over the four experimental sessions. However, differences in perceived workload associated with conjunctive and single-featured coding will remain constant over the four experimental sessions.

Using SWAT ratings as a measure of perceived workload, there were no interaction effects between practice and information presentation form ($p = .8415$). Hypothesis H6b, then, was partially supported by the results of this study. As expected, practice did not modify the relative impact of alphabetic and color coding on perceived workload. However, contrary to expectations, practice also failed to modify the relative impact of single-featured and conjunctive coding.

5.8.7 <u>Interactive Effects of Time Stress and Suggested Decision Strategy</u>

This research assessed the interaction between time stress and the suggested decision strategy. The following two subsections repeat the hypotheses and present findings concerning the impact of the interaction on decision quality and perceived workload.

5.8.7.1 <u>Time Stress/Suggested Decision Strategy and Decision Quality</u>.

> H7a. Time pressure and heuristics treatment will interact such that the difference in decision quality related to heuristics treatment will be greater under high time pressure than under moderate time pressure.

The results of this study suggest that time stress and the suggested decision strategy do interact. Using the ratio of team score to model score as a measure, the heuristics treatment and time pressure interacted such that, under high time pressure, teams with heuristics (68.6 percent of model) did little better than teams without heuristics (65.7 percent of model); however, under moderate time pressure, teams with heuristics scored significantly higher (82.4 percent of model) than did teams without heuristics (76.6 percent of model) ($p = .0300$).

Using the proportion of 2-player-2-points-per-player event completed as a behavioral measure, there was a three-way interaction among the heuristics, time stress, and practice variables ($p = .0036$). Table 5.16 provides the proportions of these events completed by teams with and without heuristics during each session under high and moderate time stress. For comparison, the model completed about 4.3 percent of the 4-point events. Figure 5.2 graphically illustrates the interaction. Except during session 1 under moderate time pressure (when teams with or without heuristics completed about the same number of 4-point events), teams with heuristics consistently completed a very low proportion of 4-point events. The highest proportions of 4-point events completed by teams without heuristics were in sessions 2 and 3 under moderate time stress; the lowest proportion for teams without heuristics was in session 3 under high time stress. The results suggest that teams with heuristics learned quickly to ignore 4-point events; beyond session 1, time stress had little impact on the proportion completed. Except under moderate time pressure in session 1, teams without heuristics consistently completed a higher proportion of 4-point events than did teams with heuristics; the magnitude of the difference varied depending on both practice and time stress. Under high time stress, teams without heuristics completed a moderate number of 4-point events except for a lower proportion in session 3; under moderate time stress, teams without heuristics completed a moderate number of 4-point events in sessions 1 and 4 and a higher proportion in sessions 2 and 3.

TABLE 5.16 Time*sess*heur Effects on Completing 4-Point Events

	Session 1	Session 2	Session 3	Session 4
With heuristics				
High stress	0.3%	0.7%	1.0%	1.0%
Moderate stress	3.8%	1.0%	1.7%	1.7%
Without heuristics				
High stress	5.2%	4.8%	2.1%	4.2%
Moderate stress	3.2%	7.7%	7.0%	4.2%

Hypothesis H7a, then, was not supported by the results of this study. The interaction between time stress and the suggested decision strategy did affect decision quality, but not in the expected direction. The suggested decision strategy had a greater impact on overall performance under moderate time pressure than under high time pressure. The specific behavioral impact on completing 4-point events depended on practice.

5.8.7.2 <u>Time Stress/Suggested Decision Strategy and Perceived Workload</u>.

> H7b. Time pressure and heuristics treatment will interact such that the difference in perceived workload related to heuristics treatment will be greater under high time pressure than under moderate time pressure.

Using SWAT ratings as a measure, the interaction between time stress and the suggested decision strategy had no significant effects on perceived workload ($p = .4490$). Hypothesis H7b, then, was not supported by the results of this study; time pressure did not modify the impact of the suggested decision strategy on perceived workload.

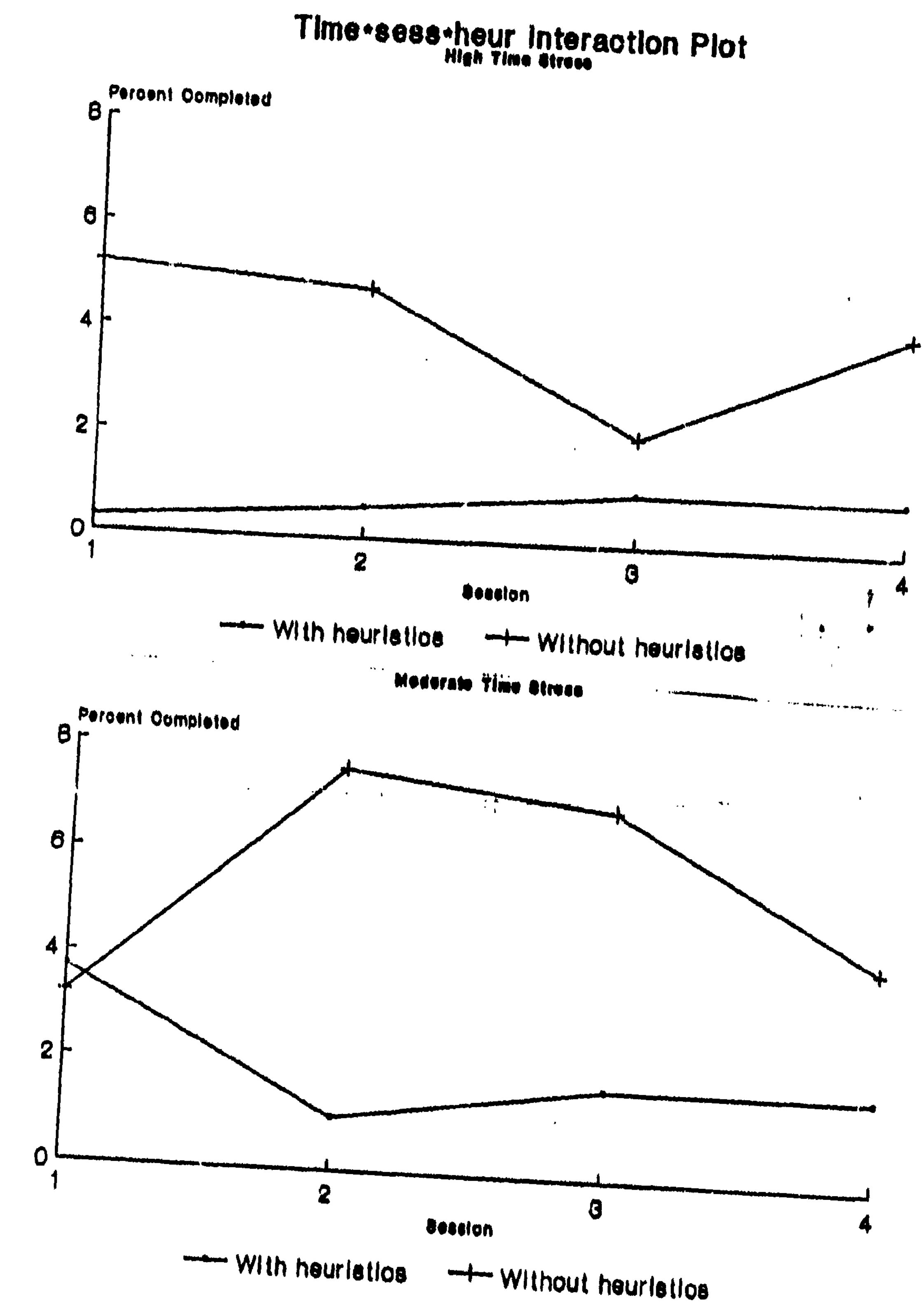

Figure 5.2 4-Point Events

5.8.8 Interactive Effects of Practice and Suggested Decision Strategy

This research assessed the interaction between practice and the suggested decision strategy. The following two subsections repeat the hypotheses and present findings concerning the impact of the interaction on decision quality and perceived workload.

5.8.8.1 Practice/Suggested Decision Strategy and Decision Quality.

> H8a. Practice and the suggested decision strategy will interact such that the advantage with provision and discussion of decision heuristics will attenuate over the four experimental sessions.

The results of this study suggest that there are no interaction effects between practice and the suggested decision strategy on decision quality except for the three-way heur*time*sess interaction effect on completing 2-player-2-points-per-player events (see Section 5.8.6.1). Using the ratio of team score to model score as a measure, practice and the heuristics treatment did not interact ($p = .9185$). There was also no interaction between practice and the suggested decision strategy using the ratio of a team's points earned from certain-valued events to the team's total points as a behavioral measure ($p = .0964$). Hypothesis H8a, then, was not supported by the results of this study. In other words, the heuristics were effective immediately, and teams with heuristics retained their advantage throughout the experiment.

5.8.8.2 Practice/Suggested Decision Strategy and Perceived Workload.

> H8b. Practice and the suggested decision strategy will interact such that differences in perceived workload between teams with and those without provision and discussion of decision heuristics will attenuate over the four experimental sessions.

Using SWAT ratings as a measure of perceived workload, there were no interaction effects between practice and the suggested decision strategy ($p = .3892$). Hypothesis H8b, then, was not supported by the results of this study; practice did not modify the impact of the suggested decision strategy on perceived workload.

5.8.9 Relative Effects of Information Presentation Form and Suggested Decision Strategy

This research compared the impact of information presentation form and the suggested decision strategy. The following two subsections repeat the hypotheses and present findings concerning the relative effects of the two variables on decision quality and perceived workload.

5.8.9.1 Information Presentation Form vs. Suggested Decision Strategy and Decision Quality.

> H9a. The magnitude of impact on decision quality related to information presentation form and to the suggested decision strategy will be the same.

The most important finding of this study is that, although no significant effects of information presentation form on decision quality were detected, heuristics did positively affect decision quality in a dynamic group intellective task involving uncertainty. Therefore, hypothesis H9a concerning the relative effects of the two treatments on decision quality was not supported; the suggested decision strategy had a greater impact on decision quality than did the information presentation form.

5.8.9.2 Information Presentation Form vs. Suggested Decision Strategy and Perceived Workload.

> H9b. The magnitude of impact on perceived workload related to information presentation form and to the suggested decision strategy will be the same.

No significant effects of either information presentation form or the suggested decision strategy on perceived workload were detected. Therefore, hypothesis H9b concerning the relative effects of the two treatments on perceived workload was supported.

5.9 Summary of Results

The most important finding of this study was that, in a dynamic group choice task, heuristics had a much greater positive impact on decision quality than did varying the coding scheme by which decision data was presented. Other findings include the following:

-- Neither information presentation form nor heuristics had an impact on SWAT measures of perceived workload.

-- Groups performed better and perceived lower levels of workload under moderate time pressure than under high time pressure.

-- Groups performed better and perceived lower levels of workload with practice.

-- Neither time stress nor practice modified the finding that information presentation form had no effect on either decision quality or perceived workload.

-- Heuristics had a greater effect on decision quality under moderate time stress than under high time stress. However, time stress did not modify the finding that heuristics had no effect on perceived workload.

-- Practice did not change the effects of heuristics on decision quality nor did it modify the finding that heuristics had no effect on perceived workload.

This chapter presented a statistical analysis of the results of the research. Tl next chapter places the findings in the context of the conceptual model and the relevant literature and discusses research implications of the results.

6.0 DISCUSSION OF RESULTS AND CONCLUSIONS

The first section of this chapter presents a discussion of the research findings. The discussion is followed by a summary of the overall conclusions from this research.

6.1 Discussion of Results

This section opens with a discussion of the most important result of the study, which concerns the relative impact on decision quality of decision process aids and information presentation forms. The opening subsection is followed by a discussion of other findings. A third subsection briefly presents some observational findings not clearly related to any of the hypotheses.

6.1.1 Discussion of Primary Result

The most important finding of this research is that, in a dynamic group intellective task, the impact on decision quality of aids which guided the decision process was much greater than the impact of the form in which information was presented. In the context of the conceptual model for this study, direct interventions in the decision making process by means of a suggested decision strategy had a greater ultimate impact on decision quality than did indirect interventions by means of modifications to the information presentation form.

6.1.1.1 Suggested Decision Strategy and Decision Quality. To better understand why teams with heuristics performed better than those without heuristics, videotapes of six teams (the top three and the bottom three teams selected on the basis of overall average ratios of team scores to model scores) were reviewed. None of the bottom three teams received the heuristics; the top two teams received the heuristics, and the third best team quickly developed and adopted a strategy very similar to that proposed in the heuristics. Contrasts between the top three and the bottom three teams, then, will be used to illustrate decision-making differences between teams using strategies oriented toward the heuristics and those using alternate strategies.

By providing and encouraging discussion of the heuristics, it was expected that explicit attention paid to an experience-based strategy would increase the probability that team members would recognize correct choices in the TRAP and would thereby improve decision quality. Three comparisons between the top three teams and the bottom three teams suggest that teams with the heuristics (or with a clear commitment to a heuristics-like strategy) were better prepared to recognize correct choices than were teams without the heuristics. First, the top three teams wasted less time searching for alternatives (an average of 10.9 time units per trial when no resources were committed) than did the bottom three teams (15.6 time units per trial). Second, the top three teams made poor choices (selected less than the best combination of events) less frequently (an average of 3.9 times per trial) than did the bottom three teams (8.7 times per trial). Finally, the top three teams reversed commitments (used their reset buttons) less frequently (an average of 1.6 times per trial) than did the bottom three teams (3.0 times per trial).

The link between the decision heuristics and improved performance was also hypothesized in part on the basis of providing the heuristics as a technique for reducing human bias in decision making [FISC82]. Each of the four heuristics provided was intended to overcome a specific bias evident in the performance of previous TRAP participants. Behavior differences related to each of the expected biases between teams with heuristics and those without heuristics help to explain the overall performance differences.

6.1.1.1.1 Heuristic #1. The first heuristic encouraged teams to complete high-certain-valued events as a first priority. Specifically, teams were told to look for both 3-person-5-points-per-person events and 2-person-4-points-per-person events in combination with a 5-point event for the third person. All teams, with or without heuristics, complete all or nearly all of the 3-person-5-points-per-person events. There was also no statistically significant difference between teams with heuristics and those without in the number of 2-person-4-points-per-person events completed. Reviews of the videotapes, however, suggest that teams using a heuristics-oriented strategy tended to be more selective in completing these events.

Teams without heuristics completed 42.6 percent of the total number of 2-person-4-points-per-person events; the bottom three teams in particular completed 51.2 percent. Of the available combinations of 8-

point events with 5-point events for the third person, the bottom three teams still completed 51.2 percent. Judging by their comments and actions, the bottom three teams simply sought to complete a significant number of the 2-person-4-points-per-person events. Where high-value combinations were completed, they were often discovered only because the third person went looking for a one-person event after the other team members indicated intent to commit resources to the two-person event.

By comparison, teams with heuristics completed 37.1 percent of the total number of 2-person-4-points-per-person events; the top three teams in particular completed about the same number (37.2 percent). However, of the available combinations of 8-point events with 5-point events for the third person, the top three teams completed 62.2 percent. Judging by their comments and actions, the top three teams looked for high-value <u>combinations</u> involving 2-person-4-points-per-person events.

6.1.1.1.2 <u>Heuristic #2</u>. Of the heuristics provided, the one that seemed to have the greatest overall impact was the second heuristic which guided teams toward using expected utility theory in dealing with uncertain events. As suggested by prospect theory [KAHN79], teams operating without the heuristics in this study valued certain gains over merely probable gains. Specifically, teams without heuristics earned a larger proportion of their points from certain-valued events than from uncertain events and sought additional information about fewer uncertain events than did teams with heuristics. Teams operating with the heuristics, on the other hand, handled uncertain events according to expected utility theory [KAHN79], illustrating the debiasing effects of the heuristics [FISC82].

The magnitude of the impact of the second heuristic seemed to be related to two factors. First, 20 uncertain events represent a significant proportion (31 percent) of the available events in each trial, so differences in strategy concerning uncertain events resulted in clear differences in performance. Second, differences in strategy concerning uncertain events between teams with heuristics and those without were more obvious and consistent than were differences in strategy related to any of the other heuristics. Teams with the heuristics very consistently followed the expected utility guidelines for handling uncertain events. By contrast, teams without the heuristics ranged from almost totally avoiding uncertain events to depending almost exclusively on uncertain events. Teams without the heuristics also varied greatly in their selectivity in committing resources to uncertain events subsequent to seeking additional information. For example, among the bottom three teams, one team committed resources indiscriminately to almost every uncertain event about which it sought information, one team essentially ignored uncertain events until the last two trials, and one team committed resources to uncertain events on the basis of high probability of payoff rather than high expected value.

6.1.1.1.3 Heuristic #3. The third heuristic encouraged teams to ignore low-certain-valued events. As expected, teams with heuristics completed a statistically significant lower number of low-valued events than did teams without heuristics. The bottom three teams completed more than three times as many low-valued events as did the top three teams. Given the small proportion of low-valued events completed even by teams without heuristics, however, the direct impact of this heuristic was limited. The average difference in points earned from low-valued events between teams with heuristics and those without was less than 1.1 points per trial. An indirect impact of the heuristic was that teams with heuristics committed resources to more valuable events while teams without heuristics were committed to earning that 1 point per trial, but there is no clear mechanism for placing a value on the indirect benefit.

6.1.1.1.4 Heuristic #4. The fourth heuristic suggested that teams remain synchronized in committing resources to events. In other words, team members should commit individual resources to a combination of events simultaneously so that all team resources will be free for follow-on commitments simultaneously and at regular intervals. Synchronization should reduce conflicting demands on a resource and, therefore, simplify the decision-making process. In reviewing the videotapes, the occurrence of a loss of synchronization was defined to be any occasion on which a team member committed his/her resource two time units or more later than other resource commitments by the team.

On average, the top three teams lost synchronization 2.2 times per trial while the bottom three teams lost synchronization 5.6 times per trial.

6.1.1.2 Interactive Effects of Time Stress and Suggested Decision Strategy. Heuristics had a greater effect on decision quality under moderate time stress than under high time stress. Using the overall performance measure (ratio of team score to computer model score), the heuristics had a positive influence on decision quality only under moderate time pressure. Two interpretations of this finding were considered.

First, it could be that, given time to apply the heuristics, the heuristics provide a performance gain with no apparent cost in perceived workload. In other words, under high time stress, teams may have resorted to very simple decision rules, whether or not they had received the heuristics, reacting as best they could. Under moderate time pressure, teams had time to more carefully consider their alternatives and could adopt more complex decision rules, whether the decision rules were provided externally or created internally. The heuristics, then, may have focused team attention on applying a consistently 'good' set of decision rules that improved performance without making the task any more difficult than it was for teams who applied their own decision rules.

If the lack of significant impact of the heuristics on SWAT ratings is assumed to be due either to counteracting effects or to measurement problems with SWAT, a second interpretation is that some of the heuristics may have added to the demands on human information processing rather than routinizing decisions. It could be, as for the first interpretation, that under high time pressure, teams resorted to very simple, reactive strategies; teams with heuristics, whose information processing capacity may already have been taxed by the demands of the high speed task, failed to apply the whole set of heuristics. Under moderate time pressure, however, teams with the heuristics may have had greater capacity to consider and to apply the heuristics to their decisions.

Both statistical and observational findings along with skepticism about the SWAT ratings lead to favoring the second interpretation. For example, since there were no statistically significant effects of time pressure or of any interaction involving time pressure on resource commitments to uncertain events, it could be that the heuristic concerning handling of uncertain events was particularly easy to apply. If so, it may have routinized decisions about those events and become equally useful under high or moderate time pressure.

On the other hand, observations of the best three and the poorest three teams suggest that applying the heuristic to look for high-value combinations of events involving 2-person-4-points-per-person events may have been more difficult. Poor teams (all operating without heuristics) completed more 8-point events under moderate time pressure, when they had more time to choose events, than under high time pressure. For some of those 8-point events (about the same proportion as under high time pressure), the third person found a 5-point event to complete once team members had chosen to work the 8-point events. Therefore, their increased rate of completing high-value combinations simply matched their increased rate of completing 8-point events. The best teams (all operating either with the heuristics or with a heuristics-like strategy), completed the same number of 8-point events but more high-value combinations under moderate time pressure than under high time pressure. Combinations of events were apparently more difficult to identify than single events. With more time to search for high-value combinations, teams with heuristics-oriented strategies tended to complete more high-value combinations under moderate time pressure than under high time pressure. Since applying the heuristic on high-value combinations seemed difficult, applying it may have exceeded information processing capacity at the high time stress level but not at the moderate level.

Finally, the second interpretation attributes the lack of impact of the heuristics on perceived workload to one or both of two factors. The routinizing effect of one or more of the heuristics may have been counteracted by the difficulty in applying other heuristics, resulting in no net effect on perceived workload. The second factor is that SWAT ratings may not have adequately captured perceived workload.

If the second interpretation is correct, there are interesting implications for supporting dynamic intellective tasks in practice (perhaps some monitoring tasks associated with air traffic control or aircraft cockpit operations) that seem worthy of exploration. Up to some undetermined level of stress, providing decision rules to human decision makers may be sufficient to assure good performance. Beyond the point at which applying the decision rules exceeds information processing capacity, however, other mechanisms, such as invoking expert system support, may be more effective.

In future studies, the impact of the heuristics themselves on information processing capacity should be assessed. The effects of variations in the scope of the heuristics and in the form in which the heuristics are provided would help to explain the interactive effects of time stress and heuristics.

6.1.1.3 Interactive Effects of Practice and Suggested Decision Strategy. Practice did not change the effects of heuristics on decision quality nor did it modify the finding that heuristics had no effect on perceived workload. Although the results of this study failed to demonstrate statistically that practice could attenuate differences in decision quality between teams with heuristics and those without, subjective evidence suggested that some teams without the heuristics moved, at different rates, toward a heuristics-oriented strategy. The one team in the top three that did not have the heuristics adopted a similar strategy early and continued to evolve toward a strategy that closely matched the heuristics. They completed a high proportion of high-certain-valued events and combinations of events, avoided low-valued events, and remained reasonably well synchronized. They also gradually increased the number of uncertain events about which they sought additional information and became increasingly selective about committing resources to uncertain events with high expected value.

One of the bottom three teams abruptly increased attention to uncertain events in the last two trials and realized obvious improvements in their scores. Given additional trials, they may also have further refined their strategy to approach the heuristics. Other teams without the heuristics (including the other two bottom teams) seemed to settle early on a strategy and to maintain it throughout the experiment. Research about how and why some groups choose to innovate while others maintain initial strategies would be useful.

6.1.1.4 Information Presentation Form and Decision Quality. The lack of a statistically significant effect of information presentation form or of any interaction involving information presentation form on decision quality in the TRAP is an important finding. It reinforces findings that humans adapt readily to and perform consistently under a variety of task conditions [LEMA86].

The lack of statistically significant performance differences between groups using single-featured coding schemes and those using conjunctive schemes should not be taken as evidence against feature integration theory. Tests of the theory typically present objects only until participants make a response (less than 3 seconds for displays with density comparable to the TRAP displays) [TREI80]. The intent of attention research is to detect differences in the initial mental processing of the object. TRAP events, by contrast, remain visible and available for initiating resource commitments for up to 20 seconds under high time stress and up to 40 seconds under moderate time stress. The relative longevity of TRAP events provides the time for confirmation of the identity of every object. Any disadvantage in initial mental processing of TRAP events presented via any particular coding scheme may be compensated for by the opportunity to confirm the location and identity of the events.

The lack of performance differences between groups using a color coding scheme and those using an alphabetic scheme supports previous findings that there are 'no clear and consistent advantages for any one visual code set over the others' [CHRI83, p. 83]. Both color and alphabetic schemes are excellent for locating objects [DAVI83]. TRAP event longevity probably also contributes to comparable performance with either single-featured coding scheme.

6.1.1.5 Summary of Primary Result. The major research outcome suggests that efforts in both information systems research and decision support system design could benefit greatly from a focus on aiding the decision process itself. Decision support technology, particularly alternative computer-based forms of presenting information, have been the focus of many research efforts. Advances in graphics technology make research in applying the new tools tantalizing. The results of this study suggest, however, that researchers have been probing only the tip of the iceberg. A greater gain in understanding decision making and in learning how to improve decision quality depend on probing what lies beneath the surface -- the process by which decision are made.

This study illustrates the benefits of applying simple decision rules to a dynamic group intellective task involving uncertainty. Teams with heuristics (or using heuristics-oriented strategies) adopted a set of behaviors that contributed to improved decision quality. The behaviors they adopted represent departures from the biases evident among teams without the heuristics. Since the decision processes used by the groups appear to have been related to group member biases, Huber's program model seems to provide a reasonable description of the group decision process in the context of this study [HUBE81]. Further, it seems to be possible to directly intervene in the group's decision process and to overcome member biases by providing a suggested decision strategy (training).

This study should be considered as an early exploratory study of the effects of decision process interventions on group performance. Just as the need for programs of research (rather than one-shot experiments) was stressed for clarifying the impact of graphics on decision-making [DICK86, BENB86c], progress toward understanding the impact of decision heuristics will be best achieved through programs of research. Additional studies on the impact of different types of heuristics on tasks with different levels of structure are needed to fully explain the relationships of heuristics-aided decision processes to decision quality and group perceptions.

6.1.2 <u>Discussion of Other Findings</u>.

The discussion for each of the following findings explains the results in the context of relevant theory and related research findings and identifies implications of the findings for research and practice.

6.1.2.1 <u>Lack of Findings Related to Perceived Workload</u>. SWAT ratings were captured as an alternative and potentially more sensitive measure of the impact of the independent variables in the TRAP, but SWAT ratings were not, in fact, more sensitive than TRAP scores. SWAT ratings captured the largest effects (e.g., the effects of time stress), but missed many of the more interesting effects.

Observational findings suggest that SWAT ratings may not always have been a valid measure of an individual's perception of the workload imposed by a particular trial. For example, when faced with a question about the time stress imposed by a just-completed trial, some participants were heard to ask others whether the trial had been a fast or a slow one. Some participants may have applied an algorithm to routinely assign a particular rating based on the objective speed of the trial rather than on their perceptions of the stress involved. Ratings of the psychological stress (confusion, frustration, etc.) imposed by a trial may also not have been consistently valid; ratings may have been influenced by the level of performance achieved on a trial. Team conversations subsequent to low-scoring trials sometimes indicated intent to increase ratings of psychological stress, even though breakdowns in team communication or coordination rather than increased trial difficulty accounted for the low score. Other measures of workload, as well as measures of decision confidence, satisfaction with the decision process, and other perceptions, should be captured in further studies to more fully explain the impact of changing task conditions.

Given the longevity of TRAP events on the display, aspects of performing the TRAP other than locating and identifying the events may have had greater influence on workload perceptions. For example, assessing the value of committing resources to various possible combinations of events is a frequently recurring and a potentially difficult mental task in the TRAP that would not be influenced by differences in coding schemes. Any difference in the event identification workload associated with a particular coding scheme may have been overwhelmed by the demands of the more difficult value assessment task, which was the same for all coding schemes. Knowing which aspects of a task contribute most to its difficulty should aid in determining where decision aids would be most useful.

The lack of effect of the heuristics, in particular, on perceived workload may have been due in part to workload associated with applying the heuristics to a decision situation. Any contribution of the heuristics themselves to the load on the human information processing system could counteract the benefits of routinizing TRAP decisions. The net effect would then involve no apparent influence of the heuristics on perceived workload. Further studies should assess the impact of varying the scope of the suggested decision strategy.

6.1.2.2 Effects of Time Stress. Groups performed better and perceived lower levels of workload under moderate time pressure than under high time pressure. Measures of the effects of time pressure in this study reinforce similar effects in earlier studies [BROW85, WILS87]. Time pressure did make the TRAP more difficult and may, therefore, be an appropriate mechanism for manipulating task difficulty in other decision environments, particularly for dynamic intellective tasks.

This study, however, examined effects at only two levels of time stress. Especially given the finding that time pressure interacted with the heuristics such that the heuristics seemed to lose their effectiveness under high time pressure, studies are needed to examine effects at other levels of time pressure. It would be valuable, for example, to identify a point at which switching from process support via heuristics to expert system support might be appropriate. Additional studies should also assess the impact of stress associated with variables other than time pressure (e.g., fatigue, adverse working conditions, limits on communication).

6.1.2.3 Effects of Practice. Groups performed better and perceived lower levels of workload with practice. It should be noted that learning associated with the steepest part of the learning curve (the Power Law of Practice [CARD83]) may not have been reflected in the results of this study. Teams completed a training session involving briefings, competency tests, demonstrations, and practice trials prior to the start of session 1. Learning apparently continued, however, into the experimental sessions.

Practice had a positive influence on decision quality in this study, but the nature of its influence varied for different behaviors associated with decision quality. Overall performance, measured as the ratio of the team's score to the computer model's score on the same trial, reached its peak in session 3 and then maintained that level through session 4, generally following expectations based on the Power Law of Practice [CARD83] and reinforcing the results of earlier studies [BROW85, WILS87]. However, scores for behavioral factors that contribute to overall TRAP performance followed different curves. The ratio of a team's points earned from certain-valued events peaked in session 2, then returned to a level comparable to that in session 1. On the other hand, information seeking activity related to uncertain events didn't peak until session 4. Taking these two factors and the videotape review results together, the learning process could be characterized as following two phases. In the first phase, teams tend to become more efficient at handling TRAP decisions according to an initial strategy. In particular, given a bias toward certain-valued events, teams become capable of completing more certain-valued events in a given period of time. In the second phase, teams tend to make adaptations to their strategies, usually involving diverting some attention from certain-valued to uncertain events.

Workload perceptions were lowest at the same point that decision quality reached its peak (session 3), reinforcing the link to the Power Law of Practice [CARD83]. However, in session 4, workload perceptions returned to the higher level of sessions 1 and 2. It could be that the beneficial effects of learning on perceived workload in this study were confounded by fatigue effects. Sessions 1 and 2 were conducted in a single 2-hour session with just a short break in between. There was no significant difference in perceived workload between the two sessions; fatigue in session 2 could have counteracted the learning effects. Sessions 3 and 4 were conducted in another 2-hour session on a separate day. Perceived workload was at its lowest in session 3 when learning was nearly complete and the participants were fresh; with no further learning into session 4, fatigue could account for the perceptions of increased workload. Replicating this study with different scheduling approaches would help to separate the learning and fatigue effects.

6.1.3 Other Observational Findings

As indicated in Chapter 5, Kimble, McNeese, and Goodyear examined the effects of emergent leadership on TRAP performance in a study run concurrently with this experiment. They found no statistical evidence, using measures of the relative frequency and duration of talking among team members, that emergent leadership had any effect on group decision quality [KIMB87]. Reviews of the data and videotapes for the top three and bottom three teams, however, reveal some interesting patterns. During the experimental sessions, the time spent in verbal communication by the top three teams averaged nearly five times that spent by the bottom three teams. What verbal communication there was among the bottom teams, none of which had the heuristics, was dominated by one member of each team. The top two teams, both of which had the heuristics, shared verbal communication time fairly equally among two or all three team members. Communications on the third-place team, which did not have the heuristics, was dominated by one team member. These results reinforce the expectation that the heuristics would improve the likelihood that at least two team members would 'see' the correct answers in the TRAP, an intellective task for which 'truth, supported, wins' [MCGR84].

The behavior of some teams suggested that time spent in verbal communication was not an adequate measure of either communication or emergent leadership. Some teams, including several that achieved high performance scores, tended to communicate only by exception. They may have set priorities for committing resources to the various types of events during the training session or during breaks (which were not videotaped). Then during the experimental sessions, team members seemed to simply move their cursors in unison to chosen events without verbalizing directions. They verbalized, then, only when a team member deviated from the expected pattern or if a particularly noteworthy situation developed. Additional research concerning the impact of information technology on communication and leadership is needed. For example, group members in this study could see what actions other members took on the display; what effects would private screens or public screens available only on demand have on performance, communication patterns, and group leadership?

One possible mechanism of communication and leadership in the TRAP was 'leadership by cursor movement.' The videotapes were not reviewed at a level of detail sufficient to detect if a team member consistently moved his/her cursor to a display row ahead of other team members. In a visually oriented task, however, such movement could have provided a cue for others to move, and thus could have served communication and leadership purposes. Further studies could tap the richness of information from videotaped sessions to clarify the roles that communication and leadership play in dynamic group choice tasks like the TRAP.

6.2 Conclusions

The following two sections identify research implications of this study's limitations and provide a final summary of the key findings.

6.2.1 Limitations and Their Implications for Researchers

Following are some implications for future researchers based on the limitations of this study.

1. The benefits of the heuristics may have been achieved at the expense of taxing human capacity to process information. The scope of the heuristics and the means for presenting them may be important variables that should be tested in replications of this study.

2. There were indications in this study of strategy changes for some teams operating without heuristics. Further research about the nature and timing of strategy innovations among teams with and without heuristics, including an analysis of the process by which a team decides to adapt its strategy, would help to clarify how providing decision rules affects the decision process.

3. The practice variable in this study may have been confounded with fatigue effects. Replicating the study with alternative experimental session scheduling approaches would help to clarify the relative impact of practice and fatigue.

4. To the extent that speed of recognition could contribute to performance on a dynamic visual task, attention theory was a useful basis for selecting coding schemes to test. Because of the longevity of

events on the TRAP display, however, this study was not an appropriate test of feature integration theory itself (a theory of attention). A separate study would be required to detect whether the single-featured codes used actually differed from the conjunctive scheme in speed of initial event identification/location in a TRAP display.

5. SWAT ratings, as alternate measures of the impact of independent variables in this study, were not as sensitive as anticipated. It would be useful to test SWAT ratings against other measures of perceived workload for the TRAP and for other mental tasks. It would also be useful to examine effects of heuristics in the TRAP on other perceptions (satisfaction with the decision process, confidence in decisions, etc.).

6.2.2 Summary of Key Findings

The most important finding of this study was that, in a dynamic group choice task, heuristics had a much greater positive impact on decision quality than did varying the coding scheme by which decision data was presented. This result, taken in combination with the findings of Cats-Baril and Huber [CATS87], strongly suggests focusing additional development and research attention on how to directly aid the decision process (e.g., by providing decision rules). It could be that the technology by which decision information is presented is less important than how the technology is used.

A second major finding reinforces the concept that training by way of providing decision rules helps to overcome human biases in handling uncertainty [FISC82]. Decision-making groups tend to choose between certain and merely probable gains according to prospect theory rather than expected utility theory [KAHN79]. In this study, groups without heuristics also relied on a variety of strategies other than one based on expected utility to choose among probabilistic gains. Given heuristics that encouraged choosing according to expected utility, however, groups adopted the recommended strategy and thereby improved their performance. Further research should help to identify other decision environments in which training for handling uncertainty would be beneficial.

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APPENDIX A

SUBJECTIVE WORKLOAD ASSESSMENT TECHNIQUE (SWAT)

The Subjective Workload Assessment Technique (SWAT) provides a measure of mental workload associated with task performance. It was developed on the basis of additive conjoint measurement methodology for application originally to problems related to aircraft pilot workload [REID81]. It has since been validated on a variety of laboratory tasks: probability monitoring, memory update, continuous recall, spatial memory, linguistic processing, mathematical processing, grammatical reasoning, maze learning, and others [REID85].

SWAT measures workload on three dimensions: time load, mental effort load, and psychological stress load. Each dimension is judged on a three-point scale; a definition of each dimension and its associated scale follow:

<u>Time Load</u> (refers to the fraction of the total time that the subject is busy)

1. Often have spare time. Interruptions or overlap among activities occur infrequently or not at all.

2. Occasionally have spare time. Interruptions or overlap among activities occur frequently.

3. Almost never have spare time. Interruptions or overlap among activities are very frequent, or occur all the time.

<u>Mental Effort Load</u> (an index of the amount of attention or mental effort required by a task regardless of the number of tasks to be performed or any time limitation)

1. Very little conscious mental effort or concentration required. Activity is almost automatic, requiring little or no attention.

2. Moderate conscious mental effort or concentration required. Complexity of activity is moderately high due to uncertainty, unpredictability, or unfamiliarity. Considerable attention required.

3. Extensive mental effort and concentration are necessary. Very complex activity requiring total attention.

* Psychological Stress Load (refers to the contribution to total workload of any conditions that produce anxiety, frustration and confusion while performing a task or tasks)

  1. Little confusion, risk, frustration, or anxiety exists and can be easily accommodated.

  2. Moderate stress due to confusion, frustration, or anxiety noticeably adds to workload. Significant compensation is required to maintain adequate performance.

  3. High to very intense stress due to confusion, frustration, or anxiety. High to extreme determination and self-control required.

The SWAT is a two-step procedure involving a scale development phase and an event scoring phase. In the scale development phase, each subject performs a sort, ranking all 27 possible combinations of the levels of each dimension from lowest to highest workload. If there is sufficient agreement among the subjects' rankings, a single group scale is developed using conjoint analysis (group scales have been possible in all the studies to date). If there is insufficient agreement, subgroup or even individual scales may be developed.

The event scoring phase involves collecting judgments from each subject on each of the workload dimensions following completion of an activity. For this research, the scale for each dimension appeared on each subject's CRT at the end of each TRAP trial. The combination of judgments was then assigned a scale value from the scale developed in the scale development phase.

REFERENCES

REID81 Reid, G., Shingledecker, C., Nygren, T., and Eggemeier, F. 'Development of Multidimensional Subjective Measures of Workload,' Proceedings of the International Conference on Cybernetics and Society, Sponsored by IEEE Systems, Man and Cybernetics Society, Atlanta, GA, October 1981, pp. 403-406.

REID85 Reid, G. 'The Systematic Development of a Subjective Measure of Workload, Proceedings of the Ninth Congress of the International Ergonomics Association, Bournemouth, England, September 1985, pp. 109-111.

APPENDIX B

SAMPLE TRAP INSTRUCTIONS

Team Resource Allocation Problem

Alphabetic Coding

Before you take seats, please take a card which will determine whether you will be team member A, B, or C for the study. (Subjects draw cards and are seated at appropriate seats.) Each team member has his/her own display and control box at the workstation. You will communicate with your teammates through the headphones provided at the workstation. The microphones on the headsets are called lip mikes because they are intended to be kept nearly touching your lips. To hold the background noise to a minimum and to hear your voices clearly, please remember to keep the mike in this position. (Demonstrate)

GENERAL INSTRUCTIONS

This experiment is concerned with how team members work with one another to accomplish tasks. You and your teammates will work together to decide how best to allocate team resources (your work time) for the good of the team in a task which involves the processing of various targets. You will work on some targets yourself, and on other targets with one or both of your teammates. The major portion of the display will have 11 rows. Targets, represented as circles labelled A, B, C, D, and E will appear randomly in each of these 11 rows. You will earn points for the team by working on these targets before their time runs out and they leave the screen. Working on a target simply means selecting a target by using the buttons on your control box to move a cursor, pressing the start button, and waiting a few seconds for the target to be processed. Because more targets than you can possibly work on will appear on the screen, the particular targets you choose, and their point values to the team, will be quite important. Therefore, it is necessary for you to learn how the point values of targets are determined. Please listen carefully.

ALPHABETIC CODING

The point value of each target depends on two things: the number of required workers and the letter that appears on the target. Overall, the point value of a target is proportional to the number of required workers. The average value of all the targets is 3 points per person. Targets requiring one, two, or three workers are therefore worth an average value of 3, 6, or 9 points, respectively, for the team. Whether a particular target is worth this average value of 3 points per person, or somewhat more or less, depends on the letter that appears on the target.

Since the letter A suggests importance or urgency, you will see that targets coded toward the beginning of the alphabet are worth more points on the average than targets coded later in the alphabet. With this notion of alphabetic order in mind, let's examine the specific point values assigned to the different targets. (Give subjects the point values table.)

The point values assigned to the different targets are shown in the table.

-- A targets are worth 5 points per person

-- B targets are worth 4 points per person

-- C targets are worth 3 points per person

-- D targets are worth 2 points per person

-- E targets are worth 1 point per person

You should now be able to determine the point value of each target by knowing the number of required workers and the letter that appears on the target.

POINT VALUE TESTING

Because your understanding of the point values is critical to this study, I am going to have you complete a short test to demonstrate your knowledge of the point values of each target. Before taking the test please examine the summary table of the point values and feel free to ask questions about it. (Pause) Do you have any questions before you take the test?

(Give subjects the test. If any questions are missed, discuss the question with the subject to insure his understanding and then give him a new test. Repeat this procedure until all subjects have answered all the questions correctly.)

We are ready to continue. (START APPROPRIATE DEMO)

DEMONSTRATION

This is a demonstration of the TRAP task. As you can see, there are 11 rows on which targets appear at random and move across the screen from left to right. The black squares in columns A, B, and C indicate which operators are required to work on each target. The scale at the top represents 30 time units.

Working on a target is very simple. All you do is move your marker, a green asterisk, to a target row and press the start button on your response box. Work automatically begins, and after a short time (10 time units), your team will receive the appropriate number of points for completing the target. These points are automatically added to the accumulated points display (show). When you begin work on a target, a black bar will appear in that target's row. The bar represents the 10 time units required to complete processing of the target. The target will move through the bar as the processing proceeds. When the target moves out of the bar, processing of that target has been completed. In order to complete a target before it leaves the screen, you will have to start it before it reaches the black dashed line (while the target is in the opportunity window).

Work on each target can be done only by a particular team member or combination of team members. As the control box before you indicates, you are either team member A, B, or C. You can work only on those targets which have a black square in your column. If a target has more than one black square in front of it, both or all three corresponding team members will have to work on the target <u>at the same time</u> in order to complete it.

To work on a target, you must move your marker to the corresponding black square. You move the marker by pressing the buttons labeled up and down on your control box. Go ahead and move your marker around. Notice that if you press the up button when you are on the top row, your marker moves to the bottom row. Similarly, if you press the down button when you are on the bottom row, the marker moves to the top row.

Once you have the marker on the row corresponding to the target you wish to work on, all you have to do is press the start button. If you are the only team member required for that target, work automatically begins and the black square will turn yellow. However, if one or more additional team members are required for the target, the black square will turn pink. This means that you are waiting to work. Work will begin only when all the required workers for the target have moved their markers to the target and pressed their start buttons. When this occurs, all the squares will turn yellow indicating that work has begun.

While you are working on a target or waiting for another team member at a target your marker will turn red. You can move it to any row you choose in preparation for the next target you may wish to start. When you become free, your marker will return to its green color indicating that you are ready to press the start button for another target.

You may wish to stop working on a target before completing it. To do this you simply press the RESET button on your control box. Your marker will turn green indicating that you are free to start another target. If others were working on the target with you, they will also have to press their RESET buttons to work on a different target. You will receive no points for targets which are not fully completed. If you choose you may begin to process the target over again, but it will take a full 10 time units to complete it. The RESET button is also used when you no longer wish to wait for other team members at a particular target.

Processing of each target takes 10 time units (TUs). A TU is some arbitrary number of seconds. The current example trial has a TU of 3 seconds. It takes 30 TUs (in this example 90 seconds) for a target to move completely across the screen. During the actual experiment, the number of seconds for a TU will be less. That is, the targets will move across the screen more quickly and the time spent processing each target will be less.

The table in the lower right hand portion of the display indicates whether each team member is free, waiting, or working. A black square indicates that a particular team member is free, while a blinking pink square indicates that a particular team member is waiting. When a particular team member is working, a numeric countdown, in TUs, will indicate how much processing time remains until the team member will be finished with the current target.

The countdown for each target will start at 30 TUs when a target is at the left-most part of the screen, and decrease at a constant rate as the target moves to the right. When a target is at the end of the opportunity window (the black dashed line), the countdown will be at 10 TUs. The target leaves the screen at 0 TU. Since each and every target requires 10 TUs for processing, knowing how many TUs a target will remain on the screen can be useful to you as you decide which targets to work on, and when to work on them. In addition, comparing this information to the countdown of team members who are currently working (show), can provide vital information about whether there will be enough time to process particular targets. For example, if a team member has 6 TUs remaining before completing a particular target, he will not be able to complete both that target and another target that currently has only 15 TUs remaining.

The object of this exercise is to accumulate as many points as possible <u>as a team</u>. This means discussing alternatives with the other members of the team in order to make optimum selection of targets. As there will be more targets than the team can possibly process, combinations of targets should be selected which optimize team performance and total point count.

TABLE B.1 TRAP Task Point Values

Target	E	D	C	B	A
Point Value (Per Person)	1	2	3	4	5

APPENDIX C

INSTRUCTIONS FOR TRAP WITH UNCERTAIN EVENTS

Now that you are familiar with the basic TRAP, we would like to introduce a variation. In order to study how teams perform with incomplete or uncertain information, we have added events for which the point value is initially unknown. The team may choose to query the system to gain more information about these events before deciding whether to commit to processing them.

The UNCERTAIN EVENTS, which appear on the screen as black rectangles, all require three persons to process them. There are two features of these events which may vary:

1. Probability of Payoff: the probability that a team will actually get the points for processing the uncertain event is either 80% (high) or 20% (low).

2. Point Value: there are two possible point values for each level of probability of payoff.

These two features taken together result in four types of uncertain events as shown in the following table:

TABLE C.1 Types of Uncertain Events

Probability of Payoff	Point Values	
High (80%)	7 (21)	3 (9)
Low (20%)	28 (84)	12 (36)

Events with a high probability of payoff, then, have an 80% probability of giving points and may be worth either 7 points per person (21 points for the team) or 3 points per person (9 points for the team). Events with a low probability of payoff have a 20% probability of giving points and may be worth either 28 points per person (84 points for the team) or 12 points per person (36 points for the team). Each of the four types of uncertain events is equally likely to occur.

There is a cost in time (2 TUs) required to get information about the events. Taking into account the time cost, the uncertain events are on the average about equivalent to a 10-point three-person event (3.3 points per person).

Initially the uncertain events appear on the screen as black rectangles with no information about the probability of payoff or point value. In order to query for information, all three members must move their markers to that row and press their start buttons, just as you would to work on an event. Two TUs after the three team members have pressed their start buttons, information about the event will appear on the black rectangle. The information will include either an H or L, for high or low probability of payoff, respectively, and the total number of points the team may earn for processing the event.

At the time the information is obtained, the team may choose to process that event, which they can initiate by pressing their start buttons a second time (uncertain events, like the other TRAP events, require 10 TUs for processing), or they may choose not to process that event, in which case they are free to move their markers to another event or events. The team may choose, if time allows, to query for information on more than one uncertain event before selecting an event or events to process.

The rules and procedures for processing the uncertain events are exactly the same as those for the standard TRAP events.

As with the basic TRAP, the object of the task is to accumulate as many points as possible as a team. This means discussing alternatives with the other members of the team in order to make optimum selection of events. The uncertain events may be viewed simply as additional alternatives. As there will be more events than the team can possibly process, combinations of events should be selected which optimize team performance (total point count).

APPENDIX D

INSTRUCTIONS FOR TRAP WITH HEURISTICS

A heuristic is a 'rule of thumb' or a simplified approach to a problem that grows out of experience with similar situations. It may not always lead to the best solution to a given problem, but it generally provides a good solution that can be identified quickly and easily. For example, an appropriate heuristic for the TRAP task might be 'Always work 3-person A targets.' People who have had experience with TRAP have suggested several heuristics for TRAP, and we encourage you to discuss and to use the heuristics as you start to perform the task.

HEURISTIC #1: In addition to 3-person A targets, look for a 2-person B target, especially with a 1-person A target.

A 2-person B target worked at the same time as a 1-person A target gets 13 points for the team. Of the 'for sure' targets, only a 3-person A target or three 1-person A targets worked at the same time get more points. Even a 1-person C target worked at the same time as a 2-person B target gets more points (11) than many combinations that may be available.

HEURISTIC #2: Next, check as many uncertain targets as you can. Immediately take L84 or H21; ignore L36 and H9.

Heuristic #2 comes from the expected value of the uncertain targets, or the average payoff you'll get for working those targets over time. Taking into account the time delay to identify the targets, the uncertain targets are worth on average about 10 points for the team. (In other words, you should take combinations of 'for sure' targets that are worth more than 10 points before you check uncertain targets.) You can compute the expected value of an individual uncertain target by multiplying the probability of payoff by the points available. For example, the expected value of an L84, once you identify it, is (0.2) x 84 = 16.8. Therefore, an L84 will only pay off one out of five times, but the payoff is big when it comes. Your score on one trial may not show the benefit of selecting an L84, but your overall average score will. An H21 also gets an expected value of 16.8, so it is just as valuable as an L84. The expected value of an L36 or an H9, though, is only 7.2, which is so low that there are almost always better options available.

HEURISTIC #3: Ignore D and E targets.

There will almost always be a better combination available than one that involves 1- and 2- point-per-person targets.

HEURISTIC #4: Keep the team synchronized. All three team members should start a target or targets at the same time.

If you can't start working a target very close to the same time as your teammates, you're better off to stay free until they are free again than to start working a 1-person target that comes along after they've started. You'd just end up in an endless round of waiting for someone to be free to start team targets.

Do you have any questions about the heuristics? (Answer questions)

You may now have 5 minutes to discuss the heuristics and any other strategies you might choose to adopt.

HEURISTICS HANDOUT

HEURISTIC #1: In addition to 3-person A targets, look for a 2-person B target, especially with a 1-person A target.

HEURISTIC #2: Next, check as many uncertain targets as you can. Immediately take L84 or H21; ignore L36 and H9.

HEURISTIC #3: Ignore D and E targets.

HEURISTIC #4: Keep the team synchronized. All three team members should start a target or targets at the same time.

APPENDIX E

CONSENT FORM

I, ____________________________, having full capacity to consent, do hereby volunteer to participate in a research study entitled, "Team Resource Allocation Problem," under the direction of Ms. Denise L. Wilson, Dr. Clifford Brown, and Maj D.J. McBride. The decision to participate in this research is completely voluntary on my part. No one has coerced or intimidated me into participating in this program. I am participating because I want to. ____________________________ has adequately answered any and all questions I have about this study, my participation, and procedures involved. I understand that ____________________________ will be available to answer any questions concerning procedures throughout this study. I understand that if significant new findings develop during the course of this research which may relate to my decision to continue participation, I will be informed. I further understand that I may withdraw this consent at any time and discontinue further participation in this study without prejudice to my entitlements. I also understand that the medical monitor of this study may terminate my participation in this study if he or she feels this to be in my best interest.

I understand that my participation in this study may be photographed, filmed or videotaped. I consent to the use of these media and understand that any records of my participation in this study may only be disclosed according to federal law, including the Federal Privacy Act, 5 USC 552a, and its implementing regulations.

I understand that my entitlement to medical care or compensation in the event of injury are governed by federal laws and regulations, and if I desire further information I may contact ____________________________.

I FULLY UNDERSTAND THAT I AM MAKING A DECISION WHETHER OR NOT TO PARTICIPATE. MY SIGNATURE INDICATES THAT I HAVE DECIDED TO PARTICIPATE HAVING READ THE INFORMATION PROVIDED ABOVE.

AM
____ PM
Signature Date Time

I have briefed the volunteer and answered questions concerning the research project.

____
Signature Date

ADDENDUM TO THE CONSENT FORM

Experiment: Team Resource Allocation Problem

You are invited to participate in an experiment designed to study how people in teams work with one another to complete a number of tasks. The situation you will be exposed to has theoretical similarity to those encountered in command, control, and communications (C^3) systems of the USAF. A better understanding of the processes by which team members complete tasks will assist in improving these C^3 systems. Your exposure to the equipment is limited to your watching the CRT screen at a distance of about two feet for approximately two hours per day for three days. This does not involve any known risks.

In the experiment, you will be observing a computer generated display of a representation of a work environment. By pressing pushbuttons on a response box you will work on tasks individually and with your team members. Because there will be more tasks available to you than you can complete, the particular tasks you and your team members choose, and when you choose them, will be of primary interest. You will receive further detailed instructions at the beginning of the experiment.

The responses you make, and the times at which you make them will be recorded for later analysis. Audio and video recordings will also be made for subsequent study. Your name will be recorded along with the dates and times at which the experiment is performed. Your confidentiality as a participant in this project will be protected. Your identity will only be revealed in accordance with the Privacy Act, 5 USC 552 and its implementing regulations. A numeric code will be used to identify the data in any publication.

Any monetary benefits will be in accordance with SRL/Air Force agreements.

You are free to refuse to participate or to withdraw your participation in the experiment at any time. Doing so will not prejudice your relation with the Laboratory in any respect.

Any questions you may have should be directed to Ms. Denise Wilson (57572) or Maj D.J. McBride (57570).

Your willingness to participate in this experiment is greatly appreciated. Your signature indicates that you have decided to participate, having read the information provided above.

YOU WILL BE GIVEN A COPY OF THIS FORM TO KEEP.

Signature Date

APPENDIX F

INSTRUCTIONS FOR SUBJECTIVE WORKLOAD ASSESSMENT TECHNIQUE

Mental workload refers to the amount of an individual's capacity that is used in the performance of a given task. The amount of capacity used depends on the individual (ability, effort, training, experience, etc.) and on the demands of the system and the task.

Among the methods available for measuring workload are performance and subjective measures. Performance measures are based on the assumption that performance declines as workload approaches the upper limit of an individual's capacity to exert effort. In other words, when workload approaches an individual's capacity, he or she begins to make errors. However, since people tend to adapt to tasks and to hold their performance constant over a range of conditions, performance measures may not reflect adequately the impact of changes in the conditions. Before performance breaks down, the individual might be working harder to avoid making errors. The individual's subjective feelings could then be used to indicate the additional effort, providing a more sensitive measure of the impact of changing task conditions.

The Subjective Workload Assessment Technique (SWAT) has been developed by the Air Force Aerospace Medical Research Laboratory to answer the need for a subjective measure of workload. SWAT is a two step process consisting of a scale development phase and an event scoring phase. During the scale development phase, participants provide the data necessary to develop a workload scale for each individual. At the event scoring phase, the individuals rate the workload associated with a particular task.

You are about to participate in the scale development phase of SWAT, which involves sorting a deck of cards. SWAT distinguishes three dimensions of workload: time load, mental effort load, and psychological stress load. For each of the three dimensions, three levels have been defined. The three levels of three dimensions yield 27 possible combinations. To help us develop your workload scale, please rank order the 27 combinations according to your own perception of the workload represented by each combination. Your rank ordering will then be converted to a personalized 0-100 workload scale by means of the mathematical procedure of conjoint analysis.

In completing your card sort, please consider the workload imposed by the combination represented on each card, and arrange the cards from the lowest through the highest workload condition. You may use any strategy that you choose in rank ordering the cards. One strategy that has proven useful to others is to first arrange the cards into a number of preliminary stacks representing 'High,' 'Moderate,' and 'Low' workload. Individual cards can be exchanged between stacks, if necessary, and then rank ordered within stacks. Stacks can then be recombined and checked to be sure that they represent your ranking of lowest to highest workload. However, the choice of strategy is up to you and you should choose the one that works best for you.

There is no 'school solution' or one correct order for this problem. The correct order is what, in your judgment, best describes the progression of workload from lowest to highest in general rather than for any specific task. That judgment differs for each of us. It is important that we are not asking for your preference on workload. Some people may prefer to be 'busy' rather than 'idle,' but we do not need to know that preference. Instead, we need information on how the three dimensions and the three levels of each one will affect the level of workload as you see it. You may prefer moderate levels over low levels of the dimensions, but the low levels should impose less workload.

You will need a description of the three dimensions of workload and definitions of the levels within each dimension to complete your card sort. I will provide that information, and you may also consult your handout. Please feel free to ask questions at any time.

TIME LOAD

Time load refers to the fraction of the total time that you are busy. When time load is low, sufficient time is available to complete all of your mental work with some time to spare. As time load increases, spare time drops out, and some aspects of performance overlap and interrupt one another. This overlap and interruption can come from performing more than one task or from different aspects of performing the same task. At higher levels of time load, aspects of performance often occur simultaneously, you are constantly busy, and interruptions are very frequent.

Time load may be judged on a three point scale:

I. Time Load

1. Often have spare time. Interruptions or overlap among activities occur infrequently or not at all.

2. Occasionally have spare time. Interruptions or overlap among activities occur frequently.

3. Almost never have spare time. Interruptions or overlap among activities are very frequent, or occur all the time.

MENTAL EFFORT LOAD

Time load refers to the amount of time one has available to perform a task or tasks. In contrast, mental effort load is an index of the amount of attention or mental effort required by a task regardless of the number of tasks to be performed or any time limitation. When mental effort load is low, the concentration and attention required by a task is minimal and performance is nearly automatic. As the demand for mental effort increases, the degree of concentration and attention required to perform increases, due to task complexity or the amount of information which must be dealt with in order to perform adequately. High mental effort load demands total attention or concentration due to task complexity or the amount of information to be dealt with.

Mental effort load may be judged on a three-point scale:

II. Mental Effort Load

1. Very little conscious mental effort or concentration required. Activity is almost automatic, requiring little or no attention.

2. Moderate conscious mental effort or concentration required. Complexity of activity is moderately high due to uncertainty, unpredictability, or unfamiliarity. Considerable attention required.

3. Extensive mental effort and concentration are necessary. Very complex activity requiring total attention.

STRESS LOAD

Stress load refers to the contribution to total workload of any conditions that produce anxiety, frustration and confusion while performing a task or tasks. At low levels of psychological stress, one feels relatively relaxed. As stress increases, confusion, anxiety, or frustration increase and greater concentration and determination are required to maintain control of the situation.

Stress may be judged on a three-point scale:

III. Stress Load

1. Little confusion, risk, frustration, or anxiety exists and can be easily accommodated.

2. Moderate stress due to confusion, frustration, or anxiety noticeably adds to workload. Significant compensation is required to maintain adequate performance.

3. High to very intense stress due to confusion, frustration, or anxiety. High to extreme determination and self-control required.

The letters you see on the back of the cards are to allow us to arrange the cards in a previously randomized sequence so that everyone gets the same order. If you examine your deck you will see the order on the back runs from A through Z and then ZZ. These letters have nothing to do with your arrangement of the cards; they simply allow us to put the cards back into the same starting sequence for the next person who sorts the deck.

During the event scoring phase, events will be rated using the same descriptors used for scale development. Asked to provide a SWAT rating for a particular event, an individual would assign either a 1, 2, or 3 to each of the three dimensions of time load, effort load, and stress load experienced during that event. The numbers for each level of the three dimensions are defined as in the scale development phase. These three ratings correspond to one of the combinations created in the ordering procedure for scale development. Your workload scale value computed for this particular combination of the three factors is then the subjective workload score assigned to the event.

From this point until you have completed the sorting will probably take 30 minutes to an hour. Please feel free to ask questions at any time. Thank you for your cooperation.

SWAT HANDOUT

I. Time Load

1. Often have spare time. Interruptions or overlap among activities occur infrequently or not at all.

2. Occasionally have spare time. Interruptions or overlap among activities occur frequently.

3. Almost never have spare time. Interruptions or overlap among activities are very frequent, or occur all the time.

II. Mental Effort Load

1. Very little conscious mental effort or concentration required. Activity is almost automatic, requiring little or no attention.

2. Moderate conscious mental effort or concentration required. Complexity of activity is moderately high due to uncertainty, unpredictability, or unfamiliarity. Considerable attention required.

3. Extensive mental effort and concentration are necessary. Very complex activity requiring total attention.

III. Stress Load

1. Little confusion, risk, frustration, or anxiety exists and can be easily accommodated.

2. Moderate stress due to confusion, frustration, or anxiety noticeably adds to workload. Significant compensation is required to maintain adequate performance.

3. High to very intense stress due to confusion, frustration, or anxiety. High to extreme determination and self-control required.

APPENDIX G

Team Resource Allocation Problem

Test of Point Value Understanding

VERSION 3

Name ______________________ Team ______ Worker: A B C

Date ______________ Session _______

One-Person Events

1. If A processes C the team will accumulate ______ points.

2. If B processes E the team will accumulate ______ points.

3. If C processes A the team will accumulate ______ points.

Two-Person Events

4. If AB together process B the team will accumulate ______ points.

5. If BC together process D the team will accumulate ______ points.

Three-Person Events

6. If ABC together process A the team will accumulate ______ points.

7. If ABC together process E the team will accumulate ______ points.

8. If ABC together process C the team will accumulate ______ points.

APPENDIX H

Team Resource Allocation Problem

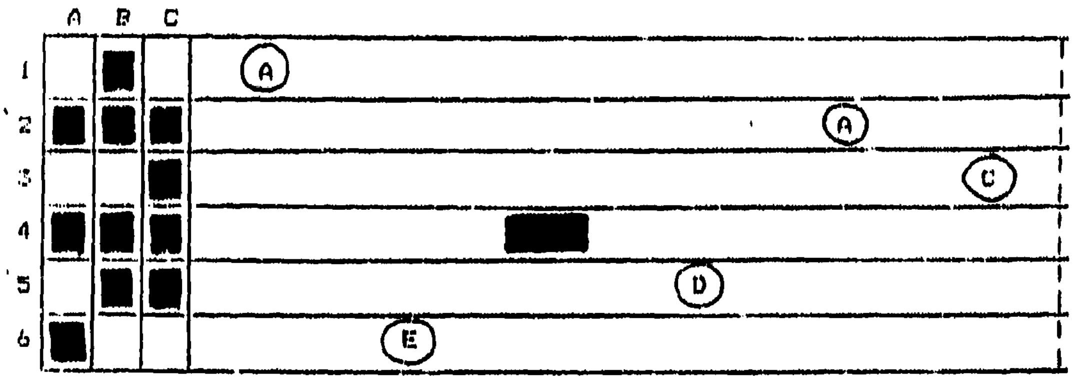
Test of Heuristics Understanding

VERSION 3

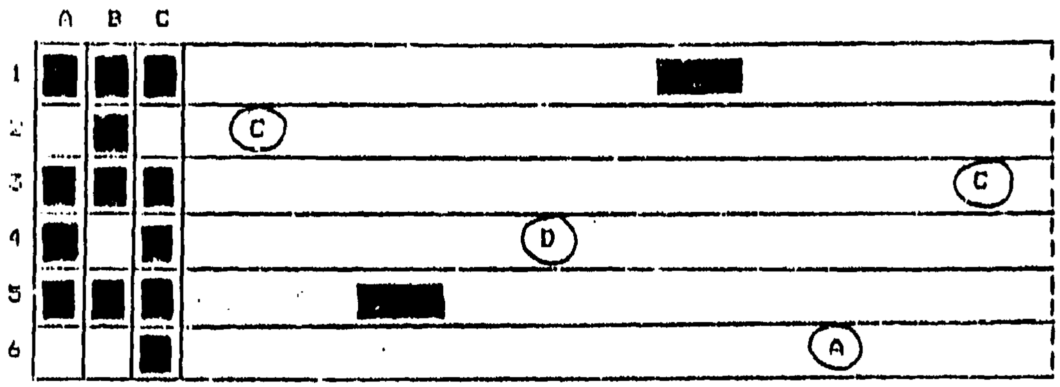
Name ______________________ Team ______ Worker: A B C

Date ______________________ Session ______

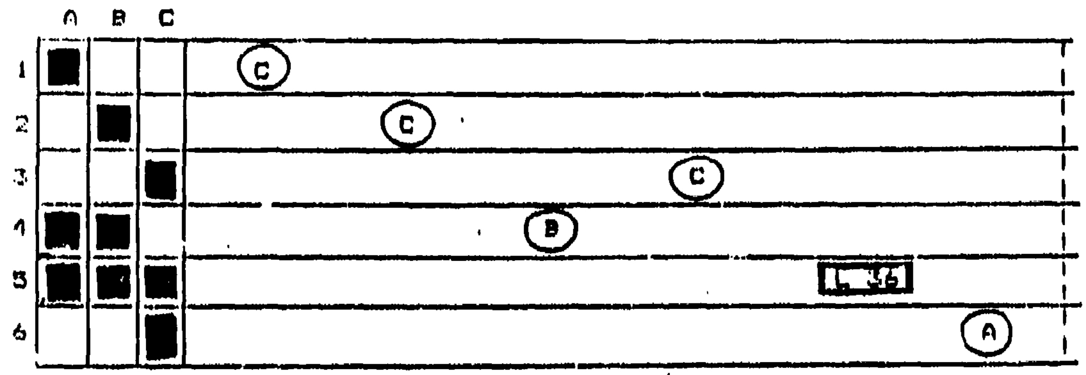
Each of the following diagrams represents a limited version of a situation you could face in the TRAP. Using the heuristics you have learned, examine each diagram, select the action that is most appropriate, and respond to the question following the diagram.



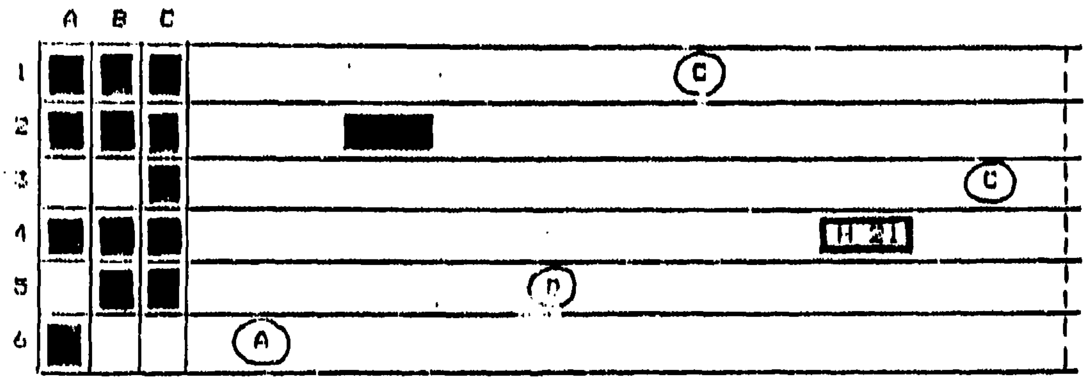
Please indicate which line or combination of lines your team should work on: ______



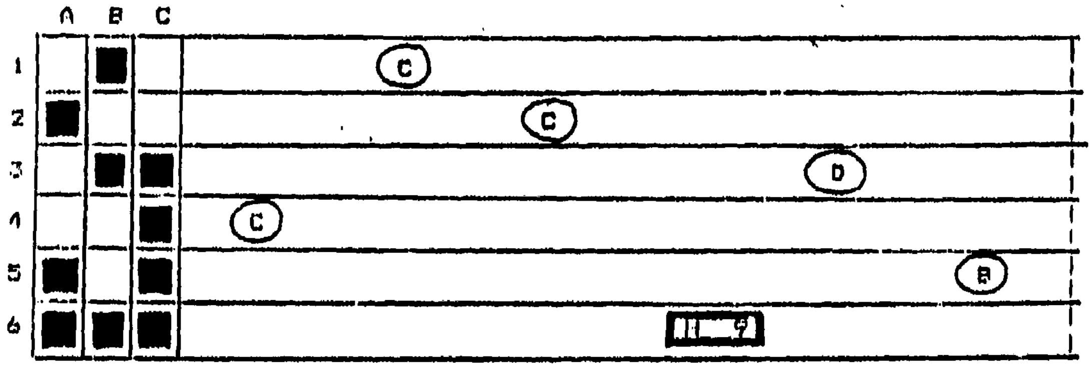
Please indicate which line or combination of lines your team should work on: ______



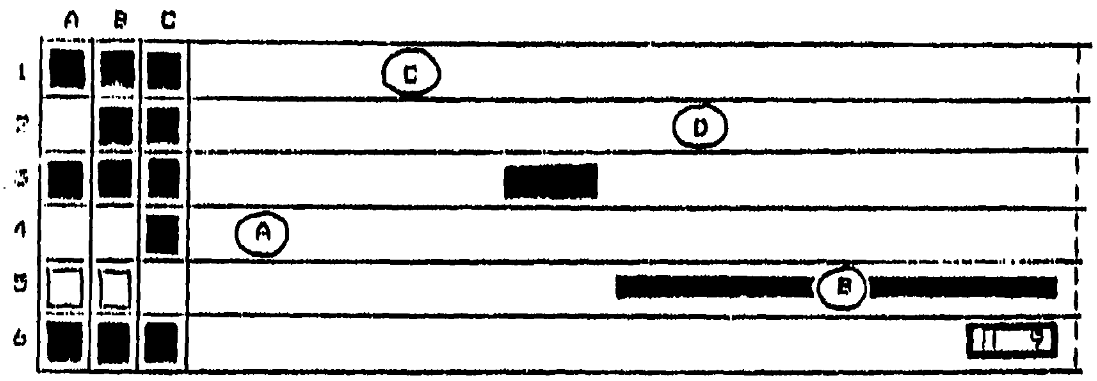
Please indicate which line or combination of lines your team should work on: ______



Please indicate which line or combination of lines your team should work on: ______



Please indicate which line or combination of lines your team should work on: ______



Please indicate the best action for person C (place an X next to the best option):

- ___ Get team to reset and start work on line 1
- ___ Suggest line 2 as next target after completing line 5
- ___ Suggest line 3 as next target after completing line 5
- ___ Start work on line 4
- ___ Get team to reset and start work on line 6

APPENDIX I
STATISTICAL RESULTS

This appendix contains the detailed results for all dependent variables used in the study. Tables I.1 through I.9 provide cell means and variances for each of the following variables:

-- SCORE = (TEAM SCORE) * 100 / (MODEL SCORE)

-- %CERT = PROPORTION CERTAIN

-- 1PL-1PT = 1 PLAYER, 1 POINT/PLAYER EVENTS

-- 2PL-2PT = 2 PLAYERS, 2 POINTS/PLAYER EVENTS

-- 2PL-4PT = 2 PLAYERS, 4 POINTS/PLAYER EVENTS

-- 3PL-5PT = 3 PLAYERS, 5 POINTS/PLAYER EVENTS

-- INFO = INFORMATION SEEKING (INFO/S1 indicates information seeking activity in experimental session 1)

-- COMMIT = RESOURCE COMMITMENTS (proportion of uncertain events to which resources are committed subsequent to seeking information)

-- SWAT

The tables of means and variances are followed by Tables I.10 and I.11, which present raw data for all variables.

TABLE I.1 CELL MEANS AND VARIANCES

SCORE = (TEAM SCORE) * 100 / (MODEL SCORE)

(n = 4)

			With Heuristics Session				Without Heuristics Session			
			1	2	3	4	1	2	3	4
Color	Fast	mean	66.5	70.2	71.8	73.7	63.4	65.8	68.3	67.3
		std	8.2	3.2	1.9	6.3	7.1	7.8	3.8	8.1
	Mod	mean	82.0	83.0	87.8	87.0	73.3	74.4	77.9	77.2
		std	6.5	2.5	4.9	4.3	6.4	3.5	8.0	6.5
Alpha	Fast	mean	65.7	64.4	73.4	68.4	63.0	64.5	66.5	66.3
		std	3.1	5.7	2.6	0.7	6.8	9.7	2.4	10.2
	Mod	mean	79.7	80.0	79.4	83.5	74.7	77.5	81.0	79.7
		std	6.2	3.7	3.4	5.2	6.2	3.1	9.8	11.4
Conj	Fast	mean	65.6	68.5	68.1	69.3	60.6	67.9	67.2	68.0
		std	7.9	7.3	3.9	3.3	4.8	4.2	1.8	4.2
	Mod	mean	78.1	81.9	82.7	84.0	76.0	74.0	77.3	75.9
		std	3.8	6.4	6.2	2.0	3.4	4.8	5.5	0.4

TABLE I.2 CELL MEANS AND VARIANCES

PROPORTION CERTAIN

(n = 4)

			With Heuristics Session 1	2	3	4	Without Heuristics Session 1	2	3	4
Color	Fast	mean	0.393	0.326	0.325	0.312	0.671	0.785	0.707	0.551
		std	0.099	0.072	0.062	0.063	0.158	0.225	0.227	0.123
	Mod	mean	0.336	0.355	0.334	0.345	0.610	0.703	0.632	0.592
		std	0.074	0.059	0.119	0.039	0.188	0.217	0.253	0.260
Alpha	Fast	mean	0.519	0.567	0.474	0.463	0.569	0.624	0.530	0.553
		std	0.144	0.155	0.126	0.101	0.262	0.195	0.313	0.248
	Mod	mean	0.521	0.524	0.508	0.459	0.505	0.558	0.464	0.479
		std	0.089	0.159	0.075	0.043	0.145	0.196	0.214	0.252
Conj	Fast	mean	0.343	0.411	0.487	0.438	0.595	0.556	0.548	0.495
		std	0.082	0.048	0.105	0.102	0.281	0.247	0.105	0.243
	Mod	mean	0.372	0.444	0.419	0.504	0.512	0.578	0.518	0.498
		std	0.052	0.027	0.098	0.053	0.163	0.174	0.210	0.183

TABLE I.3 CELL MEANS AND VARIANCES

1 PLAYER, 1 POINT/PLAYER EVENTS

(n = 4)

			With Heuristics Session				Without Heuristics Session			
			1	2	3	4	1	2	3	4
Color	Fast	mean	0.020	0.010	0.030	0.000	0.115	0.040	0.125	0.095
		std	0.023	0.020	0.020	0.000	0.099	0.046	0.173	0.073
	Mod	mean	0.030	0.030	0.020	0.010	0.115	0.170	0.128	0.115
		std	0.020	0.020	0.023	0.020	0.073	0.057	0.102	0.073
Alpha	Fast	mean	0.020	0.040	0.063	0.040	0.040	0.050	0.030	0.063
		std	0.023	0.033	0.074	0.033	0.033	0.038	0.038	0.074
	Mod	mean	0.040	0.065	0.083	0.093	0.043	0.093	0.053	0.053
		std	0.033	0.075	0.061	0.055	0.075	0.087	0.055	0.064
Conj	Fast	mean	0.010	0.000	0.010	0.083	0.060	0.073	0.073	0.063
		std	0.020	0.000	0.020	0.113	0.023	0.120	0.099	0.100
	Mod	mean	0.020	0.010	0.040	0.070	0.050	0.050	0.093	0.063
		std	0.040	0.020	0.046	0.020	0.038	0.020	0.087	0.081

TABLE I.4 CELL MEANS AND VARIANCES
2 PLAYERS, 2 POINTS/PLAYER EVENTS
(n = 4)

			With Heuristics Session				Without Heuristics Session			
			1	2	3	4	1	2	3	4
Color	Fast	mean	0.000	0.010	0.000	0.000	0.030	0.083	0.020	0.020
		std	0.000	0.020	0.000	0.000	0.038	0.091	0.040	0.023
	Mod	mean	0.010	0.000	0.000	0.020	0.033	0.095	0.095	0.073
		std	0.020	0.000	0.000	0.023	0.065	0.073	0.094	0.073
Alpha	Fast	mean	0.010	0.000	0.010	0.000	0.063	0.010	0.010	0.043
		std	0.020	0.000	0.020	0.000	0.081	0.020	0.020	0.061
	Mod	mean	0.030	0.010	0.030	0.010	0.010	0.040	0.020	0.000
		std	0.038	0.020	0.020	0.020	0.020	0.046	0.040	0.000
Conj	Fast	mean	0.000	0.010	0.020	0.030	0.063	0.053	0.033	0.063
		std	0.000	0.020	0.023	0.038	0.081	0.105	0.065	0.100
	Mod	mean	0.073	0.020	0.020	0.020	0.053	0.095	0.095	0.053
		std	0.054	0.023	0.023	0.023	0.064	0.044	0.044	0.081

TABLE I.5 CELL MEANS AND VARIANCES
2 PLAYERS, 4 POINTS/PLAYER EVENTS
(n = 4)

			With Heuristics Session 1	2	3	4	Without Heuristics Session 1	2	3	4
Color	Fast	mean	0.250	0.228	0.213	0.198	0.533	0.585	0.523	0.365
		std	0.143	0.100	0.118	0.093	0.104	0.259	0.171	0.181
	Mod	mean	0.303	0.365	0.260	0.355	0.523	0.563	0.533	0.480
		std	0.123	0.138	0.207	0.075	0.157	0.272	0.267	0.165
Alpha	Fast	mean	0.388	0.493	0.490	0.365	0.253	0.343	0.280	0.323
		std	0.334	0.265	0.251	0.179	0.224	0.272	0.301	0.327
	Mod	mean	0.573	0.553	0.520	0.543	0.345	0.470	0.313	0.315
		std	0.257	0.217	0.293	0.122	0.193	0.264	0.206	0.258
Conj	Fast	mean	0.198	0.305	0.323	0.338	0.450	0.468	0.440	0.345
		std	0.109	0.116	0.159	0.143	0.230	0.219	0.226	0.227
	Mod	mean	0.293	0.458	0.385	0.523	0.470	0.483	0.428	0.408
		std	0.107	0.107	0.124	0.110	0.188	0.156	0.232	0.174

TABLE I.6 CELL MEANS AND VARIANCES

3 PLAYERS, 5 POINTS/PLAYER EVENTS

(n = 4)

			With Heuristics Session 1	2	3	4	Without Heuristics Session 1	2	3	4
Color	Fast	mean	0.908	0.813	0.970	0.908	0.970	0.970	1.000	0.878
		std	0.119	0.239	0.060	0.119	0.060	0.060	0.000	0.102
	Mod	mean	0.908	0.908	0.875	0.845	0.938	0.875	0.940	0.845
		std	0.119	0.119	0.250	0.120	0.125	0.250	0.069	0.186
Alpha	Fast	mean	1.000	0.878	0.970	0.940	0.938	0.970	0.875	0.878
		std	0.000	0.174	0.060	0.069	0.125	0.060	0.250	0.174
	Mod	mean	0.970	0.970	0.940	0.938	0.908	0.940	0.845	0.845
		std	0.060	0.060	0.069	0.125	0.119	0.069	0.237	0.310
Conj	Fast	mean	0.908	0.970	1.000	0.908	0.845	0.875	0.815	0.815
		std	0.119	0.060	0.000	0.119	0.310	0.250	0.075	0.217
	Mod	mean	0.908	1.000	1.000	1.000	0.940	0.908	0.940	0.970
		std	0.119	0.000	0.000	0.000	0.069	0.119	0.069	0.060

TABLE I.7 CELL MEANS AND VARIANCES

INFORMATION SEEKING

(n = 1)

			With Heuristics				Without Heuristics			
			Session				Session			
			1	2	3	4	1	2	3	4
Fast	H9	mean	0.554	0.529	0.483	0.558	0.313	0.296	0.338	0.388
		std	0.151	0.168	0.111	0.172	0.146	0.227	0.180	0.163
	H21	mean	0.525	0.550	0.538	0.558	0.296	0.321	0.388	0.396
		std	0.136	0.15b	0.151	0.166	0.181	0.231	0.276	0.223
	L36	mean	0.575	0.529	0.525	0.525	0.329	0.325	0.300	0.371
		std	0.159	0.134	0.147	0.108	0.191	0.219	0.226	0.167
	L84	mean	0.521	0.525	0.538	0.621	0.325	0.292	0.325	0.383
		std	0.142	0.132	0.157	0.145	0.209	0.155	0.227	0.209
Mod	H9	mean	0.546	0.592	0.629	0.617	0.362	0.388	0.417	0.438
		std	0.116	0.133	0.125	0.183	0.176	0.238	0.205	0.229
	H21	mean	0.650	0.583	0.638	0.629	0.454	0.388	0.500	0.513
		std	0.161	0.117	0.137	0.163	0.179	0.222	0.259	0.274
	L36	mean	0.688	0.592	0.600	0.613	0.413	0.413	0.450	0.475
		std	0.196	0.200	0.109	0.164	0.204	0.247	0.290	0.244
	L84	mean	0.613	0.638	0.613	0.625	0.475	0.379	0.417	0.479
		std	0.140	0.171	0.177	0.110	0.166	0.183	0.231	0.268

TABLE I.8 CELL MEANS AND VARIANCES
RESOURCE COMMITMENTS

		With Heuristics		Without Heuristics	
		Fast	Moderate	Fast	Moderate
H9	mean	0.000	0.007	0.484	0.448
	std	0.000	0.014	0.327	0.327
H21	mean	0.910	0.952	0.945	0.955
	std	0.052	0.036	0.055	0.046
L36	mean	0.005	0.005	0.328	0.307
	std	0.011	0.013	0.389	0.348
L84	mean	0.904	0.928	0.743	0.718
	std	0.057	0.056	0.270	0.283

TABLE I.9 CELL MEANS AND VARIANCES

SWAT

(n = 4)

			With Heuristics Session 1	2	3	4	Without Heuristics Session 1	2	3	4
Color	Fast	mean	47.2	51.3	44.8	53.8	50.0	46.3	37.2	51.7
		std	3.1	3.9	8.2	8.9	23.3	13.9	8.6	10.4
	Mod	mean	34.1	38.2	29.1	35.5	31.4	34.4	23.7	33.1
		std	7.5	3.2	8.2	6.1	20.8	11.3	11.7	20.4
Alpha	Fast	mean	40.7	45.3	42.1	48.1	49.8	46.8	35.3	42.0
		std	14.6	14.9	9.7	13.5	6.8	11.4	5.4	16.7
	Mod	mean	20.8	25.8	20.7	23.3	33.3	32.1	17.5	25.7
		std	6.7	8.6	5.8	5.7	10.1	22.2	14.0	20.6
Conj	Fast	mean	51.3	52.3	47.7	49.6	42.2	49.4	44.0	50.3
		std	10.2	12.7	17.6	9.1	11.4	8.1	7.3	9.5
	Mod	mean	38.5	40.4	30.5	35.3	34.4	41.9	29.6	34.4
		std	9.4	21.5	19.4	15.7	17.3	13.5	20.6	16.8

TABLE I.10 Raw Data

Alphabetic presentation form, with heuristics

			1PL-1PT	2PL-2PT	2PL-4PT	3PL-5PT	%CERT	SCORE	SWAT
Team 1	Fast	Sess 1	0.040	0.000	0.830	1.000	0.682	63.8	58.2
		2	0.000	0.000	0.670	0.880	0.569	61.7	54.8
		3	0.040	0.040	0.710	0.880	0.567	70.2	47.0
		4	0.040	0.000	0.460	1.000	0.464	69.2	58.9
	Mod	Sess 1	0.040	0.080	0.790	1.000	0.616	79.2	30.0
		2	0.130	0.040	0.780	0.880	0.561	75.5	32.8
		3	0.080	0.040	0.750	0.880	0.554	81.7	17.3
		4	0.170	0.000	0.500	0.750	0.409	77.2	27.9
Team 2	Fast	Sess 1	0.000	0.040	0.460	1.000	0.502	70.1	41.2
		2	0.080	0.000	0.710	1.000	0.657	71.1	33.8
		3	0.170	0.000	0.580	1.000	0.509	73.6	40.6
		4	0.080	0.000	0.540	0.880	0.574	68.2	41.8
	Mod	Sess 1	0.080	0.040	0.710	1.000	0.528	82.5	15.9
		2	0.000	0.000	0.710	1.000	0.669	78.5	20.3
		3	0.170	0.000	0.790	1.000	0.582	74.4	15.8
		4	0.080	0.000	0.710	1.000	0.613	89.6	15.5
Team 3	Fast	Sess 1	0.000	0.000	0.130	1.000	0.335	65.5	22.5
		2	0.040	0.000	0.130	0.630	0.349	58.1	33.7
		3	0.000	0.000	0.130	1.000	0.288	73.4	29.2
		4	0.000	0.000	0.130	0.880	0.331	68.5	32.1
	Mod	Sess 1	0.040	0.000	0.210	0.880	0.401	71.3	21.5
		2	0.000	0.000	0.290	1.000	0.297	83.4	16.7
		3	0.040	0.040	0.210	1.000	0.416	80.4	20.8
		4	0.040	0.000	0.540	1.000	0.464	82.4	27.1
Team 4	Fast	Sess 1	0.040	0.000	0.130	1.000	0.559	63.4	40.8
		2	0.040	0.000	0.460	1.000	0.695	66.8	63.0
		3	0.040	0.000	0.540	1.000	0.534	76.6	51.6
		4	0.040	0.000	0.330	1.000	0.484	67.6	59.5
	Mod	Sess 1	0.000	0.000	0.580	1.000	0.538	85.6	15.7
		2	0.130	0.000	0.460	1.000	0.568	82.7	33.5
		3	0.040	0.040	0.330	0.880	0.481	81.2	28.8
		4	0.080	0.040	0.420	1.000	0.450	84.6	22.7

TABLE I.10, Continued

Alphabetic presentation form, without heuristics

			1PL-1PT	2PL-2PT	2PL-4PT	3PL-5PT	%CERT	SCORE	SWAT
Team 5	Fast	Sess 1	0.000	0.000	0.130	1.000	0.462	55.4	51.2
		2	0.040	0.000	0.250	1.000	0.545	59.0	43.9
		3	0.000	0.040	0.040	1.000	0.412	68.3	30.0
		4	0.000	0.000	0.040	1.000	0.560	51.8	33.7
	Mod	Sess 1	0.000	0.000	0.290	1.000	0.501	67.2	29.5
		2	0.080	0.000	0.420	1.000	0.593	73.0	14.7
		3	0.040	0.000	0.210	1.000	0.442	72.0	5.6
		4	0.000	0.000	0.130	1.000	0.443	73.5	15.6
Team 6	Fast	Sess 1	0.040	0.080	0.420	1.000	0.827	60.8	56.5
		2	0.080	0.000	0.540	1.000	0.829	66.8	38.5
		3	0.040	0.000	0.540	1.000	0.863	66.2	31.4
		4	0.040	0.130	0.580	0.880	0.776	71.9	31.4
	Mod	Sess 1	0.170	0.000	0.630	0.880	0.687	72.2	28.4
		2	0.080	0.080	0.750	1.000	0.751	79.9	28.8
		3	0.130	0.000	0.540	1.000	0.726	75.3	20.2
		4	0.130	0.000	0.630	1.000	0.782	69.8	22.4
Team 7	Fast	Sess 1	0.080	0.170	0.460	1.000	0.737	71.7	51.3
		2	0.080	0.040	0.580	1.000	0.732	77.2	63.6
		3	0.080	0.000	0.540	1.000	0.692	68.3	39.1
		4	0.170	0.040	0.630	1.000	0.672	74.5	66.9
	Mod	Sess 1	0.000	0.040	0.250	0.750	0.499	80.8	48.3
		2	0.210	0.080	0.580	0.880	0.603	79.1	64.2
		3	0.040	0.000	0.420	0.880	[illegible]	94.0	36.3
		4	0.080	0.000	0.420	1.000	0.5[illegible]2	95.6	55.4
Team 8	Fast	Sess 1	0.040	0.000	0.000	0.750	0.252	64.0	40.3
		2	0.000	0.000	0.000	0.880	0.391	55.1	41.1
		3	0.000	0.000	0.000	0.500	0.153	63.3	40.6
		4	0.040	0.000	0.040	0.630	0.205	67.0	35.7
	Mod	Sess 1	0.000	0.000	0.210	1.000	0.332	78.7	27.0
		2	0.000	0.000	0.130	0.880	0.284	77.8	20.6
		3	0.000	0.080	0.080	0.500	0.203	82.7	8.1
		4	0.000	0.000	0.080	0.380	0.170	79.8	9.2

TABLE 1.10, Continued

Color presentation form, with heuristics

			1PL-1PT	2PL-2PT	2PL-4PT	3PL-5PT	%CERT	SCORE	SWAT
Team 9	Fast	Sess 1	0.040	0.000	0.210	0.750	0.277	77.5	44.0
		2	0.040	0.040	0.290	0.500	0.258	66.3	46.8
		3	0.000	0.000	0.210	1.000	0.348	71.8	55.5
		4	0.000	0.000	0.170	0.750	0.289	68.2	55.8
	Mod	Sess 1	0.040	0.040	0.330	0.750	0.291	90.3	26.4
		2	0.040	0.000	0.290	0.880	0.336	81.8	37.5
		3	0.040	0.000	0.130	1.000	0.290	91.5	39.0
		4	0.040	0.040	0.290	0.880	0.371	91.8	40.1
Team 10	Fast	Sess 1	0.040	0.000	0.420	1.000	0.460	67.6	50.9
		2	0.000	0.000	0.290	1.000	0.411	73.3	47.5
		3	0.040	0.000	0.380	1.000	0.386	74.4	40.0
		4	0.000	0.000	0.250	1.000	0.359	77.6	46.3
	Mod	Sess 1	0.040	0.000	0.330	1.000	0.459	81.2	39.4
		2	0.040	0.000	0.500	1.000	0.417	86.6	38.5
		3	0.040	0.000	0.540	1.000	0.505	92.2	24.2
		4	0.000	0.000	0.420	1.000	0.385	83.8	27.3
Team 11	Fast	Sess 1	0.000	0.000	0.290	1.000	0.490	58.6	48.5
		2	0.000	0.000	0.250	1.000	0.361	69.1	55.9
		3	0.040	0.000	0.130	0.880	0.240	70.3	36.9
		4	0.000	0.000	0.080	0.880	0.234	80.5	65.4
	Mod	Sess 1	0.000	0.000	0.420	1.000	0.391	74.4	41.7
		2	0.040	0.000	0.460	1.000	0.385	82.8	34.5
		3	0.000	0.000	0.290	1.000	0.354	81.9	20.9
		4	0.000	0.040	0.420	0.750	0.314	82.9	40.2
Team 12	Fast	Sess 1	0.000	0.000	0.080	0.880	0.345	62.3	45.3
		2	0.000	0.000	0.080	0.750	0.275	72.2	53.0
		3	0.040	0.000	0.130	1.000	0.328	70.5	46.6
		4	0.000	0.000	0.290	1.000	0.367	68.4	47.5
	Mod	Sess 1	0.040	0.000	0.130	0.880	0.324	82.2	28.9
		2	0.000	0.000	0.210	0.750	0.282	80.9	42.2
		3	0.000	0.000	0.080	0.500	0.228	85.6	32.5
		4	0.000	0.000	0.290	0.750	0.309	89.3	34.3

TABLE I.10, Continued

Color presentation form, without heuristics

			1PL-1PT	2PL-2PT	2PL-4PT	3PL-5PT	%CERT	SCORE	SWAT
Team 13	Fast	Sess 1	0.040	0.080	0.540	0.880	0.586	72.5	28.4
		2	0.080	0.210	0.880	1.000	0.850	72.7	38.5
		3	0.080	0.000	0.630	1.000	0.741	66.1	36.1
		4	0.080	0.040	0.630	0.880	0.672	71.6	39.5
	Mod	Sess 1	0.040	0.000	0.460	1.000	0.431	81.7	12.2
		2	0.170	0.170	0.710	0.500	0.729	71.8	29.6
		3	0.130	0.130	0.710	1.000	0.767	71.6	14.6
		4	0.210	0.170	0.540	0.630	0.642	73.3	22.8
Team 14	Fast	Sess 1	0.250	0.000	0.670	1.000	0.903	56.5	34.7
		2	0.080	0.080	0.580	1.000	0.986	62.2	32.1
		3	0.380	0.080	0.670	1.000	0.987	65.2	26.3
		4	0.170	0.000	0.250	0.880	0.566	55.4	54.4
	Mod	Sess 1	0.080	0.000	0.630	1.000	0.859	69.6	14.6
		2	0.250	0.080	0.830	1.000	0.972	72.1	20.6
		3	0.250	0.210	0.790	0.880	0.916	70.5	16.7
		4	0.130	0.040	0.710	1.000	0.941	70.3	13.9
Team 15	Fast	Sess 1	0.040	0.000	0.420	1.000	0.557	65.6	57.3
		2	0.000	0.000	0.250	1.000	0.462	71.8	51.4
		3	0.000	0.000	0.290	1.000	0.437	73.6	39.5
		4	0.000	0.000	0.250	1.000	0.380	73.0	48.5
	Mod	Sess 1	0.210	0.000	0.330	1.000	0.505	75.0	50.6
		2	0.130	0.000	0.210	1.000	0.444	79.4	44.0
		3	0.000	0.000	0.210	1.000	0.370	85.3	23.1
		4	0.040	0.000	0.290	1.000	0.382	84.2	35.0
Team 16	Fast	Sess 1	0.130	0.040	0.500	1.000	0.637	59.2	79.7
		2	0.000	0.040	0.630	0.880	0.840	56.5	63.4
		3	0.040	0.000	0.500	1.000	0.664	68.5	47.0
		4	0.130	0.040	0.330	0.750	0.586	69.3	64.3
	Mod	Sess 1	0.130	0.130	0.670	0.750	0.645	68.0	48.0
		2	0.130	0.130	0.500	1.000	0.666	74.2	43.3
		3	0.130	0.040	0.420	0.880	0.475	84.5	40.5
		4	0.080	0.080	0.380	0.750	0.404	80.9	60.9

TABLE I.10, Continued

Conjunctive presentation form, with heuristics

			1PL-1PT	2PL-2PT	2PL-4PT	3PL-5PT	%CERT	SCORE	SWAT
Team 17	Fast	Sess 1	0.000	0.000	0.080	1.000	0.286	71.1	51.5
		2	0.000	0.000	0.250	1.000	0.367	71.8	50.5
		3	0.000	0.000	0.170	1.000	0.382	71.9	30.4
		4	0.000	0.040	0.130	1.000	0.342	64.8	55.2
	Mod	Sess 1	0.080	0.130	0.330	1.000	0.408	83.6	25.3
		2	0.000	0.040	0.580	1.000	0.462	85.6	21.2
		3	0.000	0.000	0.250	1.000	0.310	91.5	13.5
		4	0.080	0.040	0.540	1.000	0.517	86.6	16.1
Team 18	Fast	Sess 1	0.000	0.000	0.290	0.880	0.452	65.0	45.1
		2	0.000	0.000	0.380	0.880	0.477	66.7	38.5
		3	0.040	0.040	0.540	1.000	0.630	65.4	46.9
		4	0.250	0.000	0.380	1.000	0.553	70.9	40.6
		Sess 1	0.000	0.080	0.420	0.750	0.425	75.6	44.1
		2	0.040	0.000	0.330	1.000	0.445	72.8	25.1
		3	0.080	0.000	0.420	1.000	0.500	76.7	16.3
		4	0.080	0.040	0.420	1.000	0.456	82.5	30.6
Team 19	Fast	Sess 1	0.040	0.000	0.130	0.750	0.274	54.7	43.0
		2	0.000	0.040	0.420	1.000	0.387	76.2	51.0
		3	0.000	0.040	0.330	1.000	0.495	63.3	41.5
		4	0.040	0.080	0.460	0.880	0.493	72.5	43.4
	Mod	Sess 1	0.000	0.080	0.250	0.880	0.333	75.4	38.3
		2	0.000	0.000	0.500	1.000	0.463	87.3	47.8
		3	0.080	0.040	0.540	1.000	0.504	81.8	37.5
		4	0.080	0.000	0.670	1.000	0.573	82.5	42.1
Team 20	Fast	Sess 1	0.000	0.000	0.290	1.000	0.359	71.7	65.6
		2	0.000	0.000	0.170	1.000	0.413	59.2	69.3
		3	0.000	0.000	0.250	1.000	0.444	63.9	72.1
		4	0.040	0.000	0.380	0.750	0.363	69.1	59.3
	Mod	Sess 1	0.000	0.000	0.170	1.000	0.322	77.8	46.3
		2	0.000	0.040	0.420	1.000	0.404	81.8	67.5
		3	0.000	0.040	0.330	1.000	0.361	81.0	54.6
		4	0.040	0.000	0.460	1.000	0.468	84.4	52.6

TABLE I.10, Continued

Conjunctive presentation form, without heuristics

			1PL-1PT	2PL-2PT	2PL-4PT	3PL-5PT	%CERT	SCORE	SWAT
Team 21	Fast	Sess 1	0.040	0.000	0.170	0.380	0.221	56.9	58.6
		2	0.000	0.000	0.330	0.500	0.328	62.2	60.9
		3	0.000	0.000	0.380	0.750	0.363	69.1	52.1
		4	0.000	0.040	0.210	1.000	0.355	73.2	62.6
	Mod	Sess 1	0.000	0.000	0.250	0.880	0.312	74.2	59.2
		2	0.040	0.130	0.380	0.750	0.399	71.1	61.5
		3	0.000	0.040	0.210	1.000	0.360	82.8	56.9
		4	0.000	0.000	0.290	1.000	0.401	76.3	55.9
Team 22	Fast	Sess 1	0.040	0.080	0.540	1.000	0.714	65.5	41.1
		2	0.000	0.000	0.420	1.000	0.608	71.6	46.9
		3	0.210	0.000	0.500	0.880	0.610	68.3	35.2
		4	0.040	0.000	0.330	0.500	0.553	67.7	41.8
	Mod	Sess 1	0.040	0.080	0.460	0.880	0.550	80.3	25.6
		2	0.040	0.080	0.380	1.000	0.581	79.4	39.6
		3	0.080	0.130	0.420	0.880	0.603	77.8	9.4
		4	0.080	0.040	0.460	1.000	0.526	76.0	18.8
Team 23	Fast	Sess 1	0.080	0.000	0.380	1.000	0.565	56.1	36.5
		2	0.040	0.000	0.330	1.000	0.406	70.3	48.1
		3	0.000	0.000	0.170	0.750	0.337	65.4	47.1
		4	0.000	0.000	0.170	0.880	0.262	68.2	52.9
	Mod	Sess 1	0.080	0.000	0.460	1.000	0.480	72.4	32.4
		2	0.040	0.040	0.460	1.000	0.519	76.6	30.8
		3	0.080	0.130	0.330	0.880	0.333	78.9	32.8
		4	0.000	0.000	0.250	1.000	0.324	76.0	39.4
Team 24	Fast	Sess 1	0.080	0.170	0.710	1.000	0.881	64.1	32.8
		2	0.250	0.210	0.790	1.000	0.882	67.4	41.9
		3	0.080	0.130	0.710	0.880	0.883	65.9	41.5
		4	0.210	0.210	0.670	0.880	0.810	63.0	44.0
	Mod	Sess 1	0.080	0.130	0.710	1.000	0.706	76.9	20.2
		2	0.080	0.130	0.710	0.880	0.814	69.1	35.8
		3	0.210	0.080	0.750	1.000	0.774	69.7	19.4
		4	0.170	0.170	0.630	0.880	0.743	75.3	23.5

TABLE I.11 Raw Data, Uncertain Events

Alphabetic presentation form, with heuristics

			INFO/S1	INFO/S2	INFO/S3	INFO/S4	COMMIT
Team 1	H21	Fast	0.300	0.450	0.400	0.550	0.882
		Mod	0.400	0.400	0.450	0.550	0.917
	H9	Fast	0.250	0.350	0.500	0.400	0.000
		Mod	0.350	0.450	0.600	0.550	0.000
	L36	Fast	0.300	0.350	0.300	0.350	0.000
		Mod	0.300	0.350	0.500	0.550	0.000
	L84	Fast	0.200	0.350	0.350	0.600	0.933
		Mod	0.450	0.450	0.500	0.750	0.930
Team 2	H21	Fast	0.400	0.350	0.250	0.400	0.821
		Mod	0.650	0.400	0.550	0.600	0.909
	H9	Fast	0.450	0.450	0.500	0.350	0.000
		Mod	0.500	0.400	0.500	0.250	0.000
	L36	Fast	0.350	0.450	0.300	0.550	0.030
		Mod	0.650	0.350	0.650	0.400	0.000
	L84	Fast	0.600	0.400	0.650	0.400	0.927
		Mod	0.350	0.300	0.500	0.500	0.909
Team 3	H21	Fast	0.700	0.550	0.800	0.600	0.887
		Mod	0.750	0.750	0.500	0.450	0.918
	H9	Fast	0.500	0.600	0.350	0.750	0.000
		Mod	0.500	0.700	0.700	0.700	0.000
	L36	Fast	0.700	0.600	0.450	0.600	0.000
		Mod	0.800	0.750	0.600	0.650	0.000
	L84	Fast	0.450	0.650	0.650	0.600	0.915
		Mod	0.550	0.750	0.650	0.700	0.962
Team 4	H21	Fast	0.350	0.300	0.500	0.650	0.972
		Mod	0.550	0.550	0.550	0.700	0.979
	H9	Fast	0.450	0.550	0.350	0.750	0.000
		Mod	0.350	0.650	0.650	0.450	0.024
	L36	Fast	0.550	0.550	0.650	0.550	0.000
		Mod	0.300	0.500	0.700	0.550	0.000
	L84	Fast	0.350	0.300	0.400	0.350	0.893
		Mod	0.550	0.500	0.550	0.600	0.818

TABLE I.11, Continued

Alphabetic presentation form, without heuristics

			INFO/S1	INFO/S2	INFO/S3	INFO/S4	COMMIT
Team 5	H21	Fast	0.400	0.500	0.650	0.400	1.000
		Mod	0.650	0.500	0.750	0.750	1.000
	H9	Fast	0.450	0.500	0.600	0.550	0.762
		Mod	0.700	0.500	0.500	0.550	0.756
	L36	Fast	0.600	0.550	0.600	0.450	0.023
		Mod	0.600	0.550	0.900	0.700	0.000
	L84	Fast	0.650	0.400	0.550	0.650	0.133
		Mod	0.700	0.500	0.550	0.700	0.061
Team 6	H21	Fast	0.200	0.100	0.150	0.150	0.833
		Mod	0.300	0.300	0.300	0.150	0.905
	H9	Fast	0.050	0.150	0.200	0.150	0.909
		Mod	0.150	0.200	0.350	0.300	0.900
	L36	Fast	0.250	0.250	0.050	0.100	0.462
		Mod	0.250	0.150	0.200	0.250	0.353
	L84	Fast	0.200	0.200	0.100	0.150	0.538
		Mod	0.500	0.200	0.150	0.100	0.526
Team 7	H21	Fast	0.350	0.300	0.200	0.250	0.955
		Mod	0.500	0.450	0.450	0.500	1.000
	H9	Fast	0.250	0.250	0.400	0.150	0.571
		Mod	0.300	0.250	0.350	0.350	0.440
	L36	Fast	0.150	0.100	0.250	0.450	0.053
		Mod	0.350	0.400	0.300	0.650	0.118
	L84	Fast	0.050	0.150	0.250	0.350	1.000
		Mod	0.450	0.300	0.600	0.550	0.921
Team 8	H21	Fast	0.650	0.500	0.850	0.750	0.945
		Mod	0.700	0.750	0.900	0.950	0.970
	H9	Fast	0.450	0.650	0.550	0.500	0.163
		Mod	0.550	0.700	0.750	0.650	0.094
	L36	Fast	0.550	0.600	0.650	0.550	0.149
		Mod	0.650	0.700	0.750	0.800	0.138
	L84	Fast	0.550	0.450	0.650	0.650	0.783
		Mod	0.700	0.700	0.750	0.700	0.877

TABLE I.11, Continued

Color presentation form, with heuristics

			INFO/S1	INFO/S2	INFO/S3	INFO/S4	COMMIT
Team 9	H21	Fast	0.700	0.700	0.700	0.550	0.943
		Mod	0.900	0.700	0.750	0.550	0.983
	H9	Fast	0.700	0.550	0.550	0.750	0.000
		Mod	0.600	0.300	0.600	0.850	0.000
	L36	Fast	0.600	0.800	0.750	0.650	0.000
		Mod	0.750	0.750	0.650	0.700	0.000
	L84	Fast	0.650	0.650	0.550	0.750	0.942
		Mod	0.750	0.700	0.850	0.850	0.968
Team 10	H21	Fast	0.500	0.650	0.600	0.450	1.000
		Mod	0.350	0.500	0.600	0.700	0.977
	H9	Fast	0.400	0.450	0.450	0.450	0.000
		Mod	0.550	0.550	0.500	0.850	0.000
	L36	Fast	0.550	0.450	0.450	0.450	0.000
		Mod	0.700	0.550	0.500	0.450	0.045
	L84	Fast	0.550	0.450	0.650	0.800	0.939
		Mod	0.750	0.800	0.500	0.600	1.000
Team 11	H21	Fast	0.500	0.700	0.650	0.850	0.852
		Mod	0.850	0.750	0.900	0.900	0.882
	H9	Fast	0.750	0.650	0.600	0.450	0.000
		Mod	0.650	0.700	0.700	0.700	0.000
	L36	Fast	0.650	0.450	0.650	0.550	0.000
		Mod	0.750	0.800	0.800	0.800	0.000
	L84	Fast	0.650	0.650	0.700	0.750	0.836
		Mod	0.750	0.700	0.550	0.550	0.882
Team 12	H21	Fast	0.550	0.800	0.600	0.750	0.889
		Mod	0.650	0.650	0.800	0.950	1.000
	H9	Fast	0.700	0.900	0.600	0.650	0.000
		Mod	0.700	0.650	0.850	0.750	0.000
	L36	Fast	0.850	0.550	0.600	0.500	0.000
		Mod	0.950	0.900	0.600	0.950	0.015
	L84	Fast	0.700	0.650	0.750	0.750	0.789
		Mod	0.800	0.900	0.950	0.700	0.866

TABLE I.11, Continued

Color presentation form, without heuristics

			INFO/S1	INFO/S2	INFO/S3	INFO/S4	COMMIT
Team 13	H21	Fast	0.450	0.100	0.150	0.300	0.950
		Mod	0.450	0.200	0.250	0.350	0.960
	H9	Fast	0.250	0.050	0.200	0.350	0.529
		Mod	0.350	0.150	0.250	0.200	0.684
	L36	Fast	0.250	0.100	0.150	0.150	0.385
		Mod	0.400	0.250	0.300	0.550	0.633
	L84	Fast	0.200	0.150	0.300	0.250	0.889
		Mod	0.500	0.250	0.200	0.150	0.818
Team 14	H21	Fast	0.000	0.000	0.000	0.200	1.000
		Mod	0.050	0.000	0.150	0.050	1.000
	H9	Fast	0.300	0.000	0.050	0.400	0.733
		Mod	0.150	0.050	0.000	0.000	0.500
	L36	Fast	0.000	0.050	0.000	0.300	1.000
		Mod	0.100	0.000	0.050	0.050	0.500
	L84	Fast	0.050	0.000	0.000	0.250	0.667
		Mod	0.150	0.100	0.050	0.200	0.400
Team 15	H21	Fast	0.200	0.700	0.550	0.850	0.929
		Mod	0.500	0.600	0.750	0.750	0.942
	H9	Fast	0.450	0.350	0.450	0.600	0.027
		Mod	0.550	0.250	0.700	0.550	0.024
	L36	Fast	0.350	0.550	0.500	0.550	0.000
		Mod	0.700	0.750	0.550	0.600	0.000
	L84	Fast	0.600	0.400	0.600	0.550	0.884
		Mod	0.500	0.600	0.650	0.700	0.939
Team 16	H21	Fast	0.400	0.200	0.450	0.300	0.963
		Mod	0.500	0.550	0.550	0.750	0.936
	H9	Fast	0.400	0.300	0.150	0.300	0.565
		Mod	0.350	0.350	0.400	0.500	0.406
	L36	Fast	0.450	0.300	0.300	0.300	0.074
		Mod	0.450	0.400	0.400	0.450	0.029
	L84	Fast	0.400	0.300	0.200	0.300	0.375
		Mod	0.600	0.300	0.500	0.550	0.513

TABLE I.11, Continued

Conjunctive presentation form, with heuristics

			INFO/S1	INFO/S2	INFO/S3	INFO/S4	COMMIT
Team 17	H21	Fast	0.700	0.550	0.600	0.750	0.942
		Mod	0.650	0.600	0.700	0.600	0.961
	H9	Fast	0.700	0.550	0.650	0.750	0.000
		Mod	0.700	0.650	0.500	0.750	0.000
	L36	Fast	0.700	0.500	0.650	0.700	0.000
		Mod	0.750	0.650	0.650	0.650	0.000
	L84	Fast	0.600	0.600	0.500	0.600	0.970
		Mod	0.600	0.600	0.850	0.500	0.980
Team 18	H21	Fast	0.450	0.500	0.400	0.350	0.882
		Mod	0.650	0.600	0.500	0.600	0.957
	H9	Fast	0.550	0.250	0.350	0.350	0.000
		Mod	0.500	0.600	0.750	0.500	0.043
	L36	Fast	0.400	0.500	0.400	0.400	0.000
		Mod	0.800	0.600	0.400	0.550	0.000
	L84	Fast	0.450	0.450	0.250	0.550	0.941
		Mod	0.500	0.550	0.450	0.600	0.881
Team 19	H21	Fast	0.600	0.650	0.450	0.350	0.902
		Mod	0.750	0.550	0.650	0.400	0.979
	H9	Fast	0.550	0.400	0.350	0.400	0.000
		Mod	0.550	0.350	0.450	0.450	0.000
	L36	Fast	0.650	0.400	0.600	0.400	0.024
		Mod	0.800	0.650	0.500	0.400	0.000
	L84	Fast	0.500	0.500	0.400	0.550	1.000
		Mod	0.600	0.600	0.400	0.500	0.976
Team 20	H21	Fast	0.550	0.400	0.500	0.450	0.947
		Mod	0.650	0.550	0.700	0.550	0.959
	H9	Fast	0.650	0.650	0.550	0.650	0.000
		Mod	0.600	0.600	0.750	0.600	0.020
	L36	Fast	0.300	0.750	0.500	0.600	0.000
		Mod	0.700	0.250	0.650	0.700	0.000
	L84	Fast	0.550	0.850	0.600	0.750	0.863
		Mod	0.700	0.800	0.600	0.650	0.964

TABLE I.11, Continued

Conjunctive presentation form, without heuristics

			INFO/S1	INFO/S2	INFO/S3	INFO/S4	COMMIT
Team 21	H21	Fast	0.400	0.400	0.400	0.550	1.000
		Mod	0.450	0.400	0.550	0.500	0.974
	H9	Fast	0.500	0.400	0.550	0.600	0.659
		Mod	0.400	0.450	0.450	0.550	0.784
	L36	Fast	0.450	0.500	0.250	0.300	0.933
		Mod	0.550	0.500	0.250	0.300	1.000
	L84	Fast	0.400	0.400	0.450	0.250	1.000
		Mod	0.450	0.400	0.450	0.350	0.970
Team 22	H21	Fast	0.200	0.300	0.500	0.500	0.900
		Mod	0.550	0.350	0.500	0.400	0.917
	H9	Fast	0.200	0.250	0.300	0.450	0.000
		Mod	0.200	0.850	0.350	0.600	0.000
	L36	Fast	0.400	0.450	0.250	0.550	0.000
		Mod	0.400	0.700	0.700	0.600	0.000
	L84	Fast	0.300	0.450	0.200	0.300	0.960
		Mod	0.450	0.500	0.350	0.650	0.897
Team 23	H21	Fast	0.250	0.650	0.700	0.650	0.867
		Mod	0.550	0.500	0.750	0.700	1.000
	H9	Fast	0.350	0.650	0.400	0.400	0.083
		Mod	0.450	0.600	0.600	0.800	0.082
	L36	Fast	0.450	0.450	0.550	0.550	0.025
		Mod	0.250	0.450	0.850	0.650	0.114
	L84	Fast	0.400	0.450	0.550	0.750	0.907
		Mod	0.500	0.500	0.600	0.900	0.760
Team 24	H21	Fast	0.050	0.100	0.050	0.050	1.000
		Mod	0.250	0.050	0.100	0.300	0.857
	H9	Fast	0.100	0.000	0.200	0.200	0.800
		Mod	0.200	0.300	0.300	0.200	0.700
	L36	Fast	0.050	0.000	0.050	0.200	0.833
		Mod	0.150	0.100	0.150	0.100	0.800
	L84	Fast	0.100	0.150	0.050	0.150	0.778
		Mod	0.200	0.200	0.150	0.200	0.933